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# THE IMPACT OF ADOPTING DIGITAL TWIN IN URBAN DEVELOPMENT

Mohammed Ali Berawi[1,2*], Perdana Miraj[2], Mustika Sari[2]

[1]*Deparment of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia*
[2]*Center for Sustainable Infrastructure Development, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia*

The construction industry, which plays a pivotal role in urban development, has undergone a significant transformation in recent years. This transformation is largely marked by the rise of digitalization, a phenomenon fundamentally altering how we design, construct, and operate our urban environments. At the forefront of this paradigm shift is the notion of Digital Twins (DT), which entails a dynamic and virtual representation of tangible assets. Urban development has witnessed a growing adoption of this innovative approach to improve cities' infrastructure planning, construction, and management. Digital Twin enables real-time simulation and monitoring, enhancing performance and more informed decision-making. Therefore, implementing Digital Twin becomes crucial in developing sustainable, efficient, citizen-centric urban environments as cities expand and transform.

There are several advantages associated with implementing Digital Twin in urban planning and development, including enhanced operational efficiency, improved resource management, and the capability to anticipate and address prospective challenges in advance. Furthermore, these platforms foster collaboration among various stakeholders, allowing for a more cohesive and comprehensive approach to urban planning. Yet, to fully harness these benefits, we must navigate significant obstacles presented by concerns such as data security, privacy, the requirement for interoperable and high-quality data, and the substantial upfront investment in technology and training. Furthermore, regulatory frameworks and standardization are required to govern Digital Twin's effective and ethical application in urban development.

Around the globe, cities at different stages of development are embracing Digital Twin to enhance urban living. These technologies are being utilized by developed cities to retrofit and optimize their pre-existing infrastructure, resulting in urban spaces that are more intelligent and adaptable. Digital Twin plays a crucial role in facilitating rapid urbanization in developing cities by aiding in designing and constructing more sustainable and resilient communities. Cities such as Amsterdam and Singapore demonstrate the capacity of Digital Twin to stimulate economic expansion, mitigate environmental degradation, and enhance urban life. However, the pace and nature of adoption vary significantly, influenced by local contexts, technological readiness, and policy frameworks.

Implementing a Digital Twin in urban development is a complex endeavor that requires careful consideration of various components. Essential elements include a robust technological infrastructure, accurate and comprehensive data collection methods, and advanced analytics capabilities. It is critical that the Digital Twin be integrated with existing systems and processes to serve its intended purpose effectively.

*Corresponding author's email: maberawi@eng.ui.ac.id
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The involvement of stakeholders is also crucial; policymakers, urban developers, and citizens need to collaborate to maximize the full potential of digital twins. Continuous monitoring and updates are also necessary to keep the Digital Twin relevant and valuable over time.

As the adoption of Digital Twins in urban development progresses, several lessons have emerged. It's clear that a one-size-fits-all approach does not work; each city must tailor its Digital Twin strategy to its specific needs, resources, and goals. Interdisciplinary collaboration between various stakeholders, such as urban developers, technologists, policymakers, and community members, must be prioritized. Finally, while technology is a powerful tool, it should be seen as a means to enhance the quality of life for all citizens, foster sustainable development, and create adaptable and resilient urban spaces.

As we stand in a new era of urban development, the potential of Digital Twins to revolutionize our cities is immense. By embracing this technology thoughtfully and strategically, we can look forward to more vibrant, efficient, and livable urban environments in the years to come.

**Promoting Research on Urban Development**

In this edition, the CSID Journal of Infrastructure Development proudly presents a collection of nine papers that delve into this research area, offering valuable insights and perspectives.

The first paper, written by A. Hastomo, E. Anggraheni, A. Prasetyo, and D. Sutjiningsih, examines flood management at the Cengkareng Drain estuary in Jakarta, Indonesia, highlights the need for a comprehensive approach to coastal flood management that incorporates sea-level rise and land subsidence considerations. The study recommends several strategies to enhance flood resilience, including constructing a tidal gate, implementing a mangrove restoration program, and developing a comprehensive flood warning system.

The second paper, written by M. Zein, E. Anggraheni, and D.M. Yahya, underscores the significant impact of urbanization and land cover changes on the hydrological behavior of the Ciliwung watershed in Indonesia, highlighting the need for sustainable urban planning and effective water management strategies to mitigate future flood risks in the region. These findings emphasize the critical importance of understanding the impact of urbanization on hydrological systems and the need for proactive measures to address the associated flood risks in the Ciliwung River Watershed.

The third paper, written by H.C. Wilyalodia, E.V. Tybeyuliana, A.P.D. Mahendra, M.A. Pratama, S. Rahmawati, J.A. Fajri, and S. Mursidik, employed a meticulous method for determining microplastic abundance in the Ciliwung River. It involved examining filter papers under a microscope supplemented by a digital camera for precision in counting and recording. These findings contribute to the growing body of knowledge on microplastic pollution in river systems and provide valuable insights for policymakers, environmental agencies, and researchers working to address this pressing environmental issue.

The fourth paper, written by M.A. Pratama and D.M. Constantine, focuses on the spatiotemporal analysis of organic pollutants in the Ciliwung River, Indonesia, particularly emphasizing BOD, COD, TSS, and DO concentrations. The study utilizes flow and water quality data from the Ciliwung-Cisadane River Basin Center to comprehensively analyze the river's water quality. The study highlights the significant impact of residential development and associated wastewater on river pollution, emphasizing the urgent need to develop and implement centralized wastewater management infrastructure to address the increasing pollution load, particularly in urban areas.

The fifth paper, written by Alviansyah, E. Hadian, and W.A. Syahputra, examines the implementation of a teleworking policy with a work-from-home (WFH) scheme from a private company perspective and its implications on Greater Jakarta's proposed urban rail network's

carrying capacity. This finding highlights the resilience of the current urban rail network plans against substantial shifts in working patterns and provides insights for future urban transport planning in the context of evolving work modalities.

The sixth paper, written by A.R. Harani, B.E. Mekarwangi, and M.I. Hasan, explores the multifaceted elements involved in the design of residential buildings, encompassing both landed and high-rise structures, with a particular focus on memory. The manifestation of memory is elucidated through three key dimensions: Spatial arrangements, cultural influences, and the thoughtful consideration of collective activities. These dimensions collectively form a comprehensive framework for developing high-rise residential structures that prioritize and enhance the social bonds among their residents.

The seventh paper, written by W. Dunu, tried to formulate efficient and sustainable maintenance, repair, and management strategies for RC structures grappling with the concurrent impacts of degradation. The study proposes enhancements to prior research endeavors in this domain. While additional data is requisite to ascertain the cumulative influence of ASR and corrosion, conducting a comparative analysis of fluid transport rates through ASR-susceptible and ASR-non-susceptible concretes offers valuable insights into the maintenance and restoration of RC structures afflicted by both corrosion and ASR mechanisms such as ASR and corrosion.

The eighth paper, written by G.H. Gebru, investigates the state of outdoor green infrastructures (GI) in Aksum, Ethiopia, employing qualitative and quantitative approaches to address the disconnect between the expanding urban fabric and sustainable green space development. The research proposes a conceptual design for an interconnected GI, integrating various urban spaces into a cohesive green network. This design aims to remedy the fragmentation and enhance the environmental, social, and economic aspects of urban life in Aksum.

The ninth paper, written by C. Kabwe, M. Innocent, and F. Muleya, evaluates the infrastructure development plans in Zambia's newly established districts, primarily focusing on assessing their effectiveness. This research underscores the vital importance of infrastructure development, as it creates the foundation for an improved quality of life encompassing health, education, water supply, sanitation, and transportation.

We hope this edition may convey new insight and knowledge that benefit our readers. We welcome any comments or inquiries that you may have concerning the direction and the content of this journal. We invite you to join our venture by sending your work for future consideration.

Warmest regards from the Editorial Office,

Prof. Mohammed Ali Berawi
Editor-in-Chief

Dr. Mustika Sari
Managing Editor

Perdana Miraj
Managing Editor

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# RECOMMENDATION ON FLOOD MANAGEMENT AT CENGKARENG DRAIN ESTUARY IN ENHANCING ESTUARY RESILIENCE TO COMPOUND HAZARD

Athena Hastomo[1, *], Evi Anggraheni[1], Adi Prasetyo[2], Dwita Sutjiningsih[1]

[1]Department of Civil Engineering, Universitas Indonesia, 16424, Indonesia
[2]Coastal Engineering Agency, Directorate General of Water Resources, 81155, Indonesia

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## ABSTRACT

Jakarta's coastal region, characterized by dense settlements and industrial zones, faces significant flood risks due to land subsidence and rising sea levels, exacerbated by human activities and climate change. This study evaluates the effectiveness of the National Capital Integrated Coastal Development (NCICD) project, which proposes embankments along Jakarta's coast for enhanced flood resilience. Focusing on the Cengkareng Drain estuary, two-dimensional HEC-RAS simulations were employed. This study incorporates various factors such as precipitation, tides, waves, rising sea levels, and land subsidence to model extreme flood scenarios. The analysis reveals key strategies to improve flood management. Firstly, introducing new pumping stations and augmenting existing ones can reduce inundation by 43.16% under present conditions and significantly up to 53.16% by 2050. Secondly, regular dredging to sustain channel capacity is crucial. Additionally, mitigating local land subsidence through stringent law enforcement and heightened public awareness is vital for long-term flood control. These findings offer actionable insights into advancing Jakarta's flood management strategies in the face of evolving environmental challenges.

*Keywords*: Coastal protection; HEC-RAS 2D; Hydrodynamic; Land subsidence; Sea level rise

## 1. INTRODUCTION

Jakarta, Indonesia's bustling capital, is uniquely positioned adjacent to Jakarta Bay, rendering it vulnerable to three primary types of flooding: pluvial, fluvial, and coastal. These flood risks are often exacerbated by simultaneous high precipitation, tidal activities, and waves, a phenomenon known as a compound hazard (Lewis et al., 2011). Covering an area of 664.01 km² and home to over 10,562,088 people (as of 2020), Jakarta's northern coastal region is densely consisted of residential areas and industrial zones (Purnama et al., 2015). This concentration of development contributes to the city's economic vitality while also amplifies the potential for significant property and infrastructure damage during flood events.

In response to these challenges, the Indonesian government has initiated the National Capital Integrated Coastal Development (NCICD) master plan to enhance coastal resilience. A key component of this plan involves constructing and reinforcing embankments spanning 36 km along Jakarta's coast and 100 km along its rivers (Kementerian Koordinator Bidang Perekonomian Republik Indonesia, 2014). These embankments are designed to be a structural shield for the coast, integrated seamlessly with the existing urban infrastructure.

*Corresponding author's email: athena.hastomo@ui.ac.id, Tel. +62-812-8414-9640
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A crucial site within this plan is the Cengkareng Drain Estuary, a significant floodway in Jakarta. The proposed embankments here necessitate thorough evaluation to ascertain their effectiveness and potential areas for improvement. While factors like tidal activities, waves, and precipitation are accounted for in the planning, emerging challenges such as sea-level rise (SLR) and land subsidence (LS) due to climate change and urbanization, respectively, pose additional risks (Pasquier et al., 2019; Prasetyo et al., 2019). These evolving factors could diminish the efficacy of structural solutions like embankments, underscoring the need for a comprehensive approach to coastal flood management incorporating SLR and LS considerations.

This study aims to enhance coastal resilience by refining the existing NCICD plan. We will focus on developing recommendations using the two-dimensional Hydrologic Engineering Center-River Analysis System (HEC-RAS) model to evaluate and optimize flood management strategies at the Cengkareng Drain Estuary.

## 2. LITERATURE STUDY

### 2.1. Design Rainfall

The analysis of hydrological processes, characterized by temporal variability, is a dynamic approach to represent changing environmental conditions accurately. This approach often called the stochastic method, is particularly relevant in rainfall data analysis (Soewarno, 1995). Selecting an appropriate distribution model is crucial as it must accurately reflect the specific conditions of the location under study. Harto (2000) emphasizes that errors in choosing the right distribution can lead to significant overestimations or underestimations of design rainfall values. Commonly used rainfall distribution models and their respective formulas are as follows (Soewarno, 1995):

Normal Distribution:

$$x_t = \bar{x} + K_t S_x \tag{1}$$

Log-Normal Distribution:

$$\log x_t = \log \bar{x} + K_t S_x \tag{2}$$

Gumbel Distribution:

$$x_t = \bar{x} + \frac{(Y_t - Y_n)}{S_n} S_x \tag{3}$$

Log Pearson Type III Distribution:

$$\log x_t = \overline{\log x} + K_t S_{\log x} \tag{4}$$

Where $x_t$ is design rainfall with $t$ years return period (mm), $\bar{x}$is average rainfall (mm), $K_t$ is standard variable for $t$ years return period, $S_x$ is standard deviation (mm), $Y_t$ is a reduced variable, $Y_n$ is average reduced variable, and $S_n$ is reduced standard deviation.

### 2.2. Admiralty Method

Tidal movements, a key natural phenomenon in marine environments, involve the vertical motion of seawater from the surface down to the seabed. These movements are primarily driven by gravitational forces and centrifugal effects (Surinati, 2007). Several methods can be employed to calculate tidal harmonic components, each suited to different data length requirements. While the Least Square Method is preferable for longer datasets, the Admiralty Method is effective for shorter data lengths, such as 15 or 29 days.

The Admiralty Method, a well-established harmonic approach, calculates tidal components' amplitude and phase differences (Ichsari et al., 2020). It analyzes major tidal components, including M2, S2, N2, K1, O1, P1, M4, MS4, and K2. These components are essential in predicting various sea level elevations, which are crucial for maritime and coastal planning, as shown in Table 1.

Table 1 Important Sea Level Elevations (Supriyadi et al., 2018)

| Elevation | Symbol | Tidal Constants |
|---|---|---|
| Highest High Water Level | HHWL | $Z_0 + (M_2 + S_2 + K_2 + K_1 + O_1 + P_1)$ |
| Mean High Water Level | MHWL | $Z_0 + (M_2 + K_1 + O_1)$ |
| Mean Low Water Level | MLWL | $Z_0 - (M_2 + K_1 + O_1)$ |
| Lowest Low Water Level | LLWL | $Z_0 - (M_2 + S_2 + K_2 + K_1 + O_1 + P_1)$ |
| Lowest Astronomical Tide | LAT | $Z_0 - (M_2 + S_2 + K_2 + K_1 + O_1 + P_1 + N_2 + Q_1)$ |

## 2.3. Design Wave

Accurately determining the design wave value is critical in coastal and ocean engineering. Two commonly used methods are the Fisher-Tippet Type I/Gumbel Method and the Weibull Method (CERC, 2006). The mathematical formulations for these methods are as follows:

$$H_m = \hat{A} y_m + \hat{B} \tag{5}$$

$$H_{sr} = \hat{A} y_r + \hat{B} \tag{6}$$

for the Fisher-Tippet Type I/Gumbel Method:

$$P(H_s \leq H_{sm}) = 1 - \frac{m - 0.44}{N_T + 0.12} \tag{7}$$

$$y_m = -\ln[-\ln P(H_s \leq H_{sm})] \tag{8}$$

$$y_r = -\ln\left[-\ln\left(1 - \frac{1}{LT_r}\right)\right] \tag{9}$$

for the Weibull Method:

$$P(H_s \leq H_{sm}) = 1 - \frac{m - 0.2 - \frac{0.27}{\sqrt{\kappa}}}{N_T + 0.2 + \frac{0.23}{\sqrt{\kappa}}} \tag{10}$$

$$y_m = -\ln[1 - P(H_s \leq H_{sm})]^{\frac{1}{\kappa}} \tag{11}$$

$$y_r = [\ln(LT_r)]^{1/\kappa} \tag{12}$$

Where $H_{sm}$ is the $m^{th}$ wave height $(m)$, $N_T$ is the total of wave events, $\kappa$ is the form parameter, $H_m$ is wave height, $A$ is the linear coefficient, $B$ is the linear constant, $y_m$ is the wave height variable, $H_{sr}$ is significant to design wave height $(m)$, $T_r$ is return period, $\kappa$ is data length, $L$ is average event per year $(N_T/K)$.

## 2.4. Sea Level Rise

Sea level rise, a notable impact of global climate change, is characterized by an increase in a region's mean sea level (MSL). This phenomenon exhibits a complex pattern, evidence were shown by several years of observational data. In Indonesia, an analysis of sea level trends from

1990 to 2019 indicates notable fluctuations, but overall, the data reveal an ascending trendline (Triana & Wahyudi, 2020). This upward trend underscores the need for continuous monitoring and projection of sea levels to accurately assess the severity and potential impacts of sea level rise in the region.

Regarding observational data, Indonesia's sea level changes have been documented through various sources, including the National Oceanic and Atmospheric Administration (NOAA). Measurements by NOAA have primarily relied on altimetry readings from the TOPEX/POSEIDON and Jason 1–3 satellite data. These sophisticated satellite-based observations have been instrumental in providing accurate and reliable data. According to the latest reports by NOAA (2022), the rate of sea level rise in Indonesia has been quantified at 4.6 ± 0.4 mm/year.

The significance of these findings is profound, particularly in the context of coastal planning and management. Understanding the rate and pattern of rising sea levels is crucial for developing effective strategies to mitigate its impacts, especially in coastal regions like Indonesia, where such changes can have far-reaching consequences.

### 2.5. Land Subsidence

Land subsidence (LS) is the gradual sinking of land, typically due to the consolidation of underlying sediment, which results in increased effective stress and subsurface soil movement. While LS can occur naturally, it is often exacerbated by human activities, notably groundwater extraction. Jakarta's densely populated coastal areas are particularly susceptible to this phenomenon. Comparative research across major Asian cities has identified Jakarta as one of the most affected by high land subsidence rates.

Several studies have been conducted to understand LS in Jakarta. For instance, research covering 1997-2005 utilized GPS observations to analyze LS characteristics. This study, led by Abidin et al. (2008), revealed that the rate of land subsidence in Jakarta varied significantly, ranging from 1-10 cm/year to as high as 15-20 cm/year. Further, geodetic GPS measurements conducted between 2014 and 2017 indicated areas where land subsidence reached an alarming rate of approximately 8 cm/year on some of the areas, amounting to a total subsidence of 24 cm over three years (Dinas Perindustrian dan Energi Pemerintah Provinsi DKI Jakarta, 2017).

The implications of land subsidence are particularly critical in coastal areas, where it is a major contributor to increased flood risk (Fiaschi & Wdowinski, 2020). Therefore, LS is a key factor in flood management and urban planning, especially in coastal regions like Jakarta, where its impact is significant and ongoing.

### 2.6. Hydrodinamic Model: HEC-RAS 2D

HEC-RAS, developed by the US Army Corps of Engineers, is a sophisticated modeling software used extensively in hydrodynamic studies. The two-dimensional (2D) HEC-RAS model employs terrain data to calculate inundation areas and depths numerically. At the core of this model are the Saint-Venant equations, which are fundamental for the conservation of mass and momentum in fluid dynamics. The equations are as follows:

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = q \tag{13}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} - f_c v = -g\frac{\partial z_s}{\partial x} + \frac{1}{h}\frac{\partial}{\partial_x}\left(v_{t,xx}h\frac{\partial u}{\partial x}\right) + \frac{1}{h}\frac{\partial}{\partial_y}\left(v_{t,yy}h\frac{\partial u}{\partial y}\right) - \frac{\tau_{b,x}}{\rho R} + \frac{\tau_{s,x}}{\rho h} \quad (14)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} - f_c u = -g\frac{\partial z_s}{\partial y} + \frac{1}{h}\frac{\partial}{\partial_x}\left(v_{t,xx}h\frac{\partial v}{\partial x}\right) + \frac{1}{h}\frac{\partial}{\partial_y}\left(v_{t,yy}h\frac{\partial v}{\partial y}\right) - \frac{\tau_{b,y}}{\rho R} + \frac{\tau_{s,y}}{\rho h} \quad (15)$$

where $h$ is water depth (m), t is time (s), u and v are specific flow in both $x$ and y directions ($\mathrm{m}^2 s^{-1}$), $g$ is the gravitational acceleration ($ms^{-2}$), $z_s$ is water elevation (m), $v_{t,xx}$ and $v_{t,yy}$ are horizontal eddy viscosity coefficient of surface wind shear stress ($\mathrm{Nm}^{-2}$), $\rho$ is density ($\mathrm{kgm}^{-3}$), $R$ is a hydraulic radius (m), and $f_c$ is Coriolis parameter ($\mathrm{rads}^{-1}$).

## 3. METHODS

### 3.1. Study Area

The Cengkareng Drain Estuary, situated in the northern part of Jakarta and adjacent to Jakarta Bay, is a critical component of Jakarta's flood management system. This estuary, lying downstream of the Pesanggrahan River, was developed as part of the 'Masterplan for Drainage and Flood Control of Jakarta.' Its primary function is to serve as one of the connector channels designed to control floods by efficiently redirecting water toward Jakarta Bay, thereby mitigating flood risks in the surrounding areas.

Covering an area of 25.58 km², the Cengkareng Drain Watershed is a densely populated region, as depicted in Figure 1. The land use map (Figure 1a) illustrates the extent of urban development in the area, a direct consequence of population growth and subsequent land use changes. These changes have primarily accommodated residential, educational, and other infrastructural needs. However, this rapid urbanization has increased impervious surfaces, exacerbating rainfall-runoff issues (Anggraheni et al., 2019).

The watershed is characterized by its flat topography and low elevation, often below mean sea level, as shown in Figure 1b. This geographical feature necessitates specialized flood protection measures. Historically, these measures have included the construction of embankments and pump stations across the polders to manage water levels effectively. Additionally, the Cengkareng Drain Estuary is particularly vulnerable to LS and SLR, compounding the risk of severe flooding.

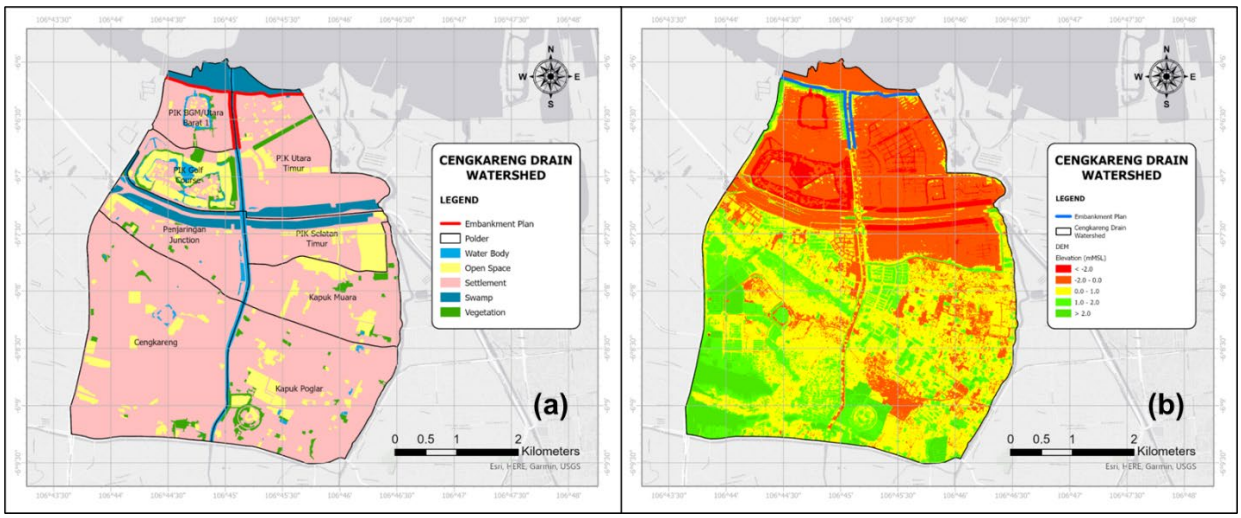



Figure 1 Cengkareng Drain Watershed: (a) Land Use, (b) Elevation

### 3.2. Data

The data in this study was used to gather the hydrodynamic simulation inputs. The required input included unsteady flow, terrain, and geometric data. The unsteady flow data includes design rainfall, tides, design waves, and sea level rise. For the design of rainfall, historical daily rainfall data was required. The data from 2003 to 2021 was obtained from the (SNVT-PTPIN 2021b). For the tide analysis, sea level data was required. This data was gathered from the (UNESCO, 2023) sensor monitoring and ranged for February 2020. For the design wave, ten years of wind data were required. The data was also obtained from the (SNVT-PTPIN, 2021a).

The terrain data includes a digital elevation model (DEM) and land subsidence. The digital elevation model was LIDAR from 2021, gathered from the Directorate General of Human Settlements. The terrain data needs to be altered to depict the effects of land subsidence on the area. Therefore, a land subsidence rate was also needed. The rate was gathered from both observation and study data. This study used two sources, one being the study from 2002-2005 (Abidin et al., 2008) and the other was the observation data from 2014-2017 (Dinas Perindustrian dan Energi Pemerintah Provinsi DKI Jakarta, 2017).

Lastly, the geometric data includes the watershed area and existing infrastructures. The location consists of polder systems. Therefore, every pump station was also modeled. The data was gathered from the Directorate General of Water Resources.

## 4. RESULTS AND DISCUSSION

### 4.1. Scenario and Parameter

To effectively evaluate flood management improvements in the Cengkareng Drain estuary, a series of scenarios, as detailed in Table 2, were developed and analyzed. These scenarios were categorized into three main groups: Scenario A Represents the baseline condition without embankment construction. Scenario B: Encompasses conditions post-embankment construction. Scenario C: Illustrates conditions with the implementation of recommended flood management measures. Additionally, each scenario was examined under varying conditions to assess the system's performance in response to projected changes and the effectiveness of the implemented recommendations. These conditions focused on whether SLR and LS were factored into the analysis.

Table 2 Simulation Scenarios and Parameters

| Scenarios | Embankment | Down-stream Boundary | Precipitation | SLR | LS | Recommendation |
|---|---|---|---|---|---|---|
| A1 | - | 100-year design wave and HHWL | 100-year design rainfall | - | - | - |
| A2 | - | | | v | Minimum | - |
| A3 | - | | | v | Maximum | - |
| B1 | v | | | - | - | - |
| B2 | v | | | v | Minimum | - |
| B3 | v | | | v | Maximum | - |
| C1 | v | | | - | - | v |
| C2 | v | | | v | Minimum | v |
| C3 | v | | | v | Maximum | v |

This structured approach to scenario analysis allows for a comprehensive understanding of the impacts of various flood management strategies under different environmental conditions. The results from these scenarios will offer insights into the effectiveness of current and proposed flood control measures in the context of evolving climatic and geophysical factors.

### 4.2. Design Rainfall Analysis

The analysis of design rainfall, a critical component in understanding flood risks, was conducted using several statistical distributions. The resultant values, as detailed in Table 3, were adjusted using the area reduction factor (ARF) to ensure accuracy in the context of the study area. To validate the appropriateness of each distribution, two statistical tests were employed: the Chi-Square and Smirnov-Kolmogorov Methods.

The results of these tests indicated that both the Log-Normal Distribution and Log Pearson Type III Distribution were acceptable. However, the Log Pearson Type III Distribution was selected as it is more commonly used in hydrological studies. This decision was also influenced by the need to align the design rainfall with the 100-year return period, corresponding to the evaluated structural design standards.

Table 3 Design Rainfall Results

| Return Period | Design Rainfall (Reduced) | | | |
|---|---|---|---|---|
| | Normal | Log-Normal | Gumbel | Log Pearson Type III |
| 2 | 91.88 | 87.01 | 87.36 | 88.25 |
| 5 | 117.66 | 116.21 | 134.65 | 116.65 |
| 10 | 131.17 | 135.24 | 142.10 | 133.94 |
| 25 | 145.60 | 159.02 | 169.66 | 154.32 |
| 50 | 154.82 | 176.33 | 190.10 | 168.56 |
| 100 | 163.41 | 194.20 | 210.38 | 182.13 |
| Chi-Square | **Accepted** | **Accepted** | **Accepted** | **Accepted** |
| Smirnov-Kolmogorov | **Rejected** | **Accepted** | **Rejected** | **Accepted** |

### 4.3. Tidal Analysis

The tidal analysis for this study was conducted using the Admiralty Method, which involved analyzing hourly sea level data from February 2020. This method was instrumental in determining key sea level elevations, which are crucial for understanding and preparing for tidal impacts. The results of this analysis are summarized in Table 4.

One of the significant outcomes of this tidal analysis was the determination of the Highest High-Water Level (HHWL). HHWL is often used as a benchmark for setting design water levels for coastal structures. In our study, the HHWL elevation was adopted as the downstream boundary condition in the simulation to represent extreme tidal conditions accurately.

Table 4 Tidal Analysis Result

| Elevation | Symbol | Chart Datum (m) | |
|---|---|---|---|
| | | MSL | LLWL |
| Highest High-Water Level | HHWL | +0.80 | +1.60 |
| Mean High Water Level | MHWL | +0.58 | +1.38 |
| Mean Sea Level | MSL | +0.00 | +0.80 |
| Mean Low Water Level | MLWL | -0.58 | +0.22 |
| Lowest Low Water Level | LLWL | -0.80 | +0.00 |

Incorporating these tidal levels into our hydrodynamic model required converting them into a time-series format, as the model operates under unsteady conditions. Thus, the derived sea level data was used to project tidal fluctuations over a 30-day period. The graphical representation of this tidal time series, including the HHWL value, is depicted in Figure 2.

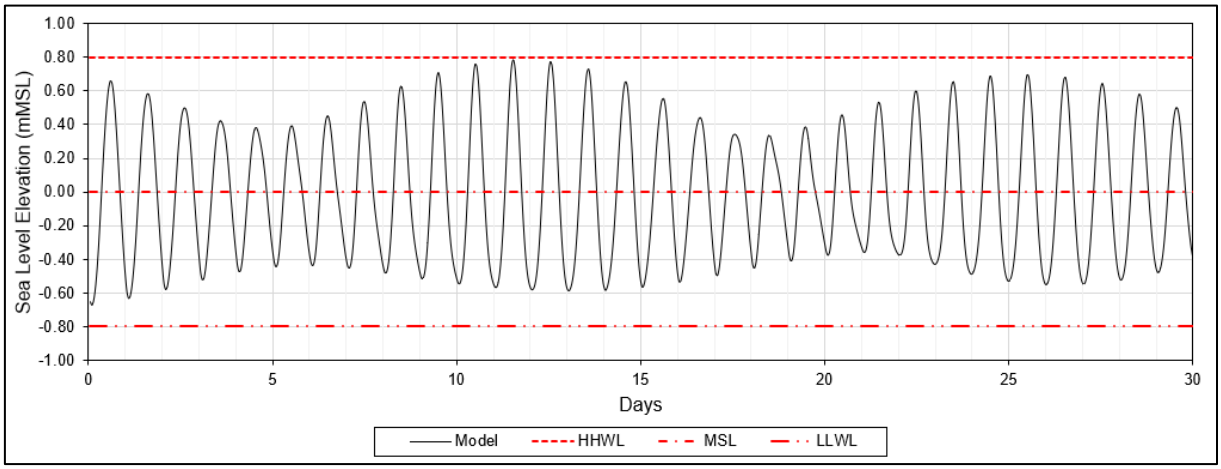



Figure 2 Predicted 30-day Tidal Time Series Data Containing HHWL

### 4.4. Design Wave Analysis

The analysis of the design wave was conducted using a decade of wind data spanning from 2011 to 2020. This extensive dataset was crucial for calculating the significant wave height for each year, thereby providing a reliable foundation for our wave analysis. Since the embankment design is based on a 100-year return period, aligning the wave analysis with this temporal benchmark was essential.

The wave height calculations were performed using two established statistical methods: the Fisher Tippet Type I/Gumbel Method and the Weibull Method. The results from these analyses are graphically represented in Figure 3. These methods determined the design wave heights to be 2.510 meters and 2.547 meters, respectively. To ensure that our model accounts for extreme conditions, the higher value of 2.547 meters was selected as the design wave height for subsequent simulations and analyses.

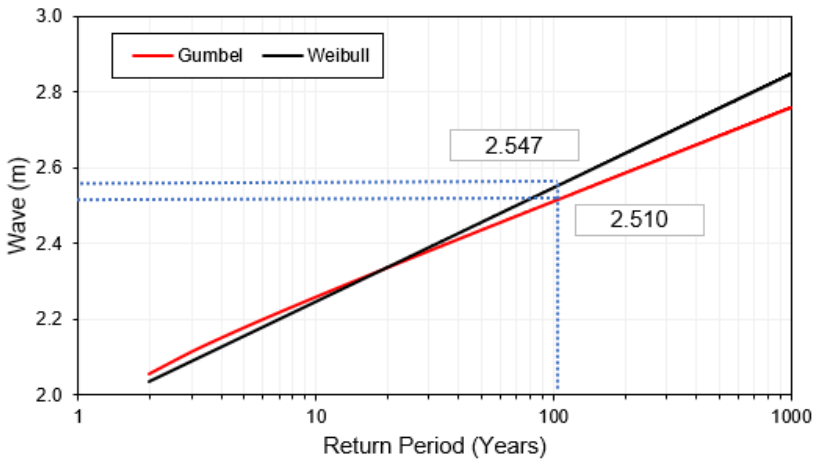



Figure 3 Design Wave Analysis Result

This approach to design wave analysis aligns with the structural design standards and provides a comprehensive understanding of the potential wave impacts under extreme conditions. This information is pivotal for assessing the effectiveness and robustness of the proposed embankment designs against significant wave events.

### 4.5. Sea Level Rise Rate

Observational data on Mean Sea Level (MSL) in Indonesia has consistently indicated an upward trend, pointing to a gradual increase in sea levels over the years. The analysis of annual changes in MSL suggests a linear progression of sea level rise (SLR). As illustrated in Figure 4, the calculated SLR rate stands at 4.86 mm/year, accompanied by a coefficient of determination ($R^2$) value of 0.80. The $R^2$ value, ranging from 0 to 1, measures the extent to which the independent variable (in this case, 'year') can predict the dependent variable (here, 'MSL increase'). This value indicates a robust correlation, providing a reliable basis for projecting future MSL changes. Based on the SLR rate, SLR was projected, as shown in Table 5.

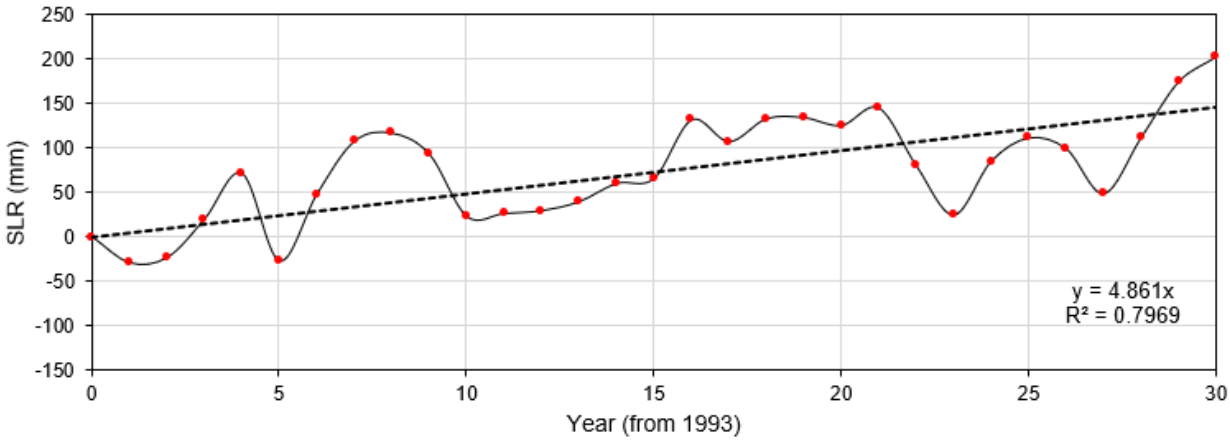



Figure 4 Sea Level Rise from 1993-2022 (NOAA, 2022)

Table 5 Linear SLR Projection

| Year | 2020 | 2050 |
|---|---|---|
| **SLR (mm)** | 0 | 145.80 |

Despite the apparent linearity in the model, it is important to acknowledge the potential for deviation from observed data. Such deviations could result in either overestimation or underestimation of MSL projections. Sea level prediction is inherently complex, influenced by factors such as global warming, extreme weather events, and even lunar cycles (Musbikhin et al., 2020). Alternative modeling approaches, including Support Vector Regression (SVR), Long Short-Term Memory (LSTM), and Autoregressive Integrated Moving Average (ARIMA), have been explored for SLR prediction (Balogun & Adebisi, 2021). Each method presents unique strengths and limitations, and further research is necessary to identify the most appropriate approach for Indonesia, considering the specific data availability and regional characteristics.

### 4.6. Land Subsidence Rate

In assessing the impact of LS on the Cengkareng Drain Estuary, projections were made based on the assumption of a consistent LS rate over time. This approach is visually depicted in Figure 5, which illustrates the observed LS rates for two distinct periods. The period from December 2002 to September 2005 (33 months) provides data for the maximum LS scenario, while the data from 2014 to 2017 (36 months) represents the minimum LS scenario. These periods were selected to capture the variability in LS rates affecting the area.

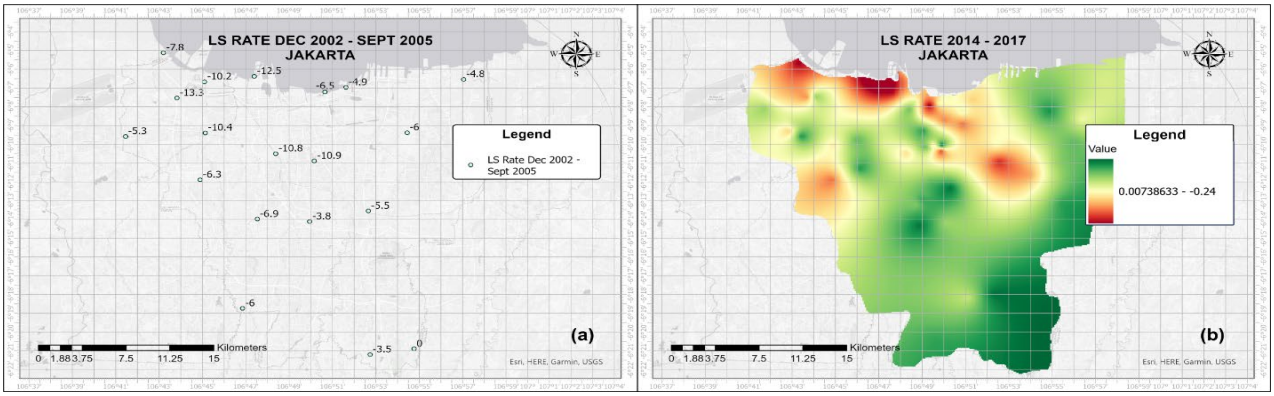



Figure 5 Land Subsidence Rate: (a) 2002-2005 (Abidin et al., 2008) (b) 2014-2017 (Dinas Perindustrian dan Energi Pemerintah Provinsi DKI Jakarta, 2017)

The terrain data was modified by overlaying the terrain with the projected LS rates to integrate LS into the hydrodynamic modeling. This modification process is illustrated in Figure 6, which demonstrates how the land elevation is altered under both minimum and maximum LS scenarios.

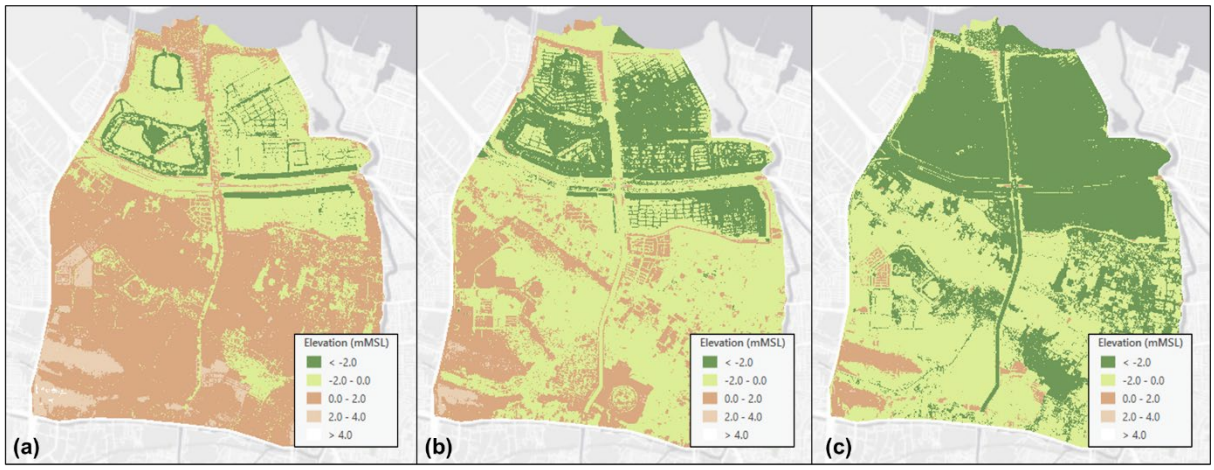



Figure 6 Terrain Modification Due to LS (a) Existing, (b) Minimum LS, (c) Maximum LS

The visualizations, particularly in Figures 6b and 6c, starkly highlight the potential impact of LS on the topography of the Cengkareng Drain Estuary. Most notably, most of the estuary is projected to fall below the mean sea level elevation under both LS scenarios. This finding underscores the critical influence of LS on the area's vulnerability to flooding and the necessity of incorporating LS considerations into flood risk management and infrastructure planning.

### 4.7. Flood Mapping: HEC-RAS 2D

The flood mapping for the Cengkareng Drain Estuary was conducted using HEC-RAS 2D, incorporating the hydrodynamic model and boundary conditions detailed earlier. This analysis produced various inundation maps corresponding to each defined scenario, shown in Figure 7.

Scenario A1 depicted inundation for the base year 2020 under compound hazards without considering the planned embankments. Scenarios A2 and A3 projected conditions for the year 2050, factoring in SLR and LS. These scenarios revealed substantial changes in the inundation area, suggesting extensive submersion in the northern part of the estuary during extreme floods. With a minimum LS rate in the 2020 base year and 2050, the embankments will still reduce the

inundation area. However, that is not the case with the last scenario. A more detailed value can be seen in Figure 8.

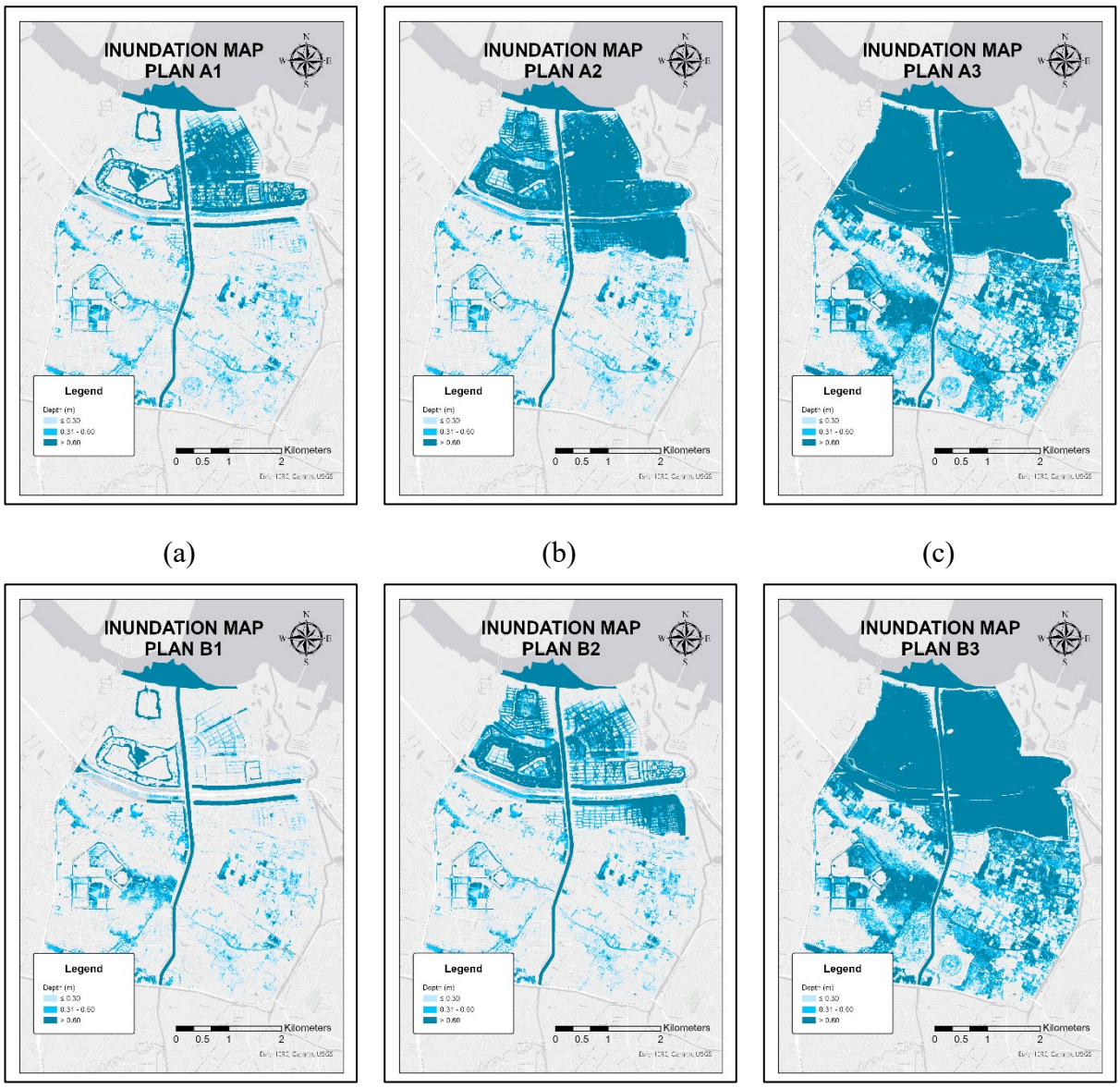



Figure 7 Inundation Map for Scenario A and B: (a) Plan A1, (b) Plan A2, (c) Plan A3, (d) Plan B1, (e) Plan B2, (f) Plan B3

Based on the result, the embankment plan demonstrated a significant reduction in inundation area by 25.19% in 2020. However, this effectiveness will diminish to between 15.42% and 0.12% by 2050 due to rising SLR and LS. The analysis highlighted that while embankments can mitigate flooding, their efficacy is compromised by increasing sea levels and subsiding land. Figure 8 compares the inundation areas between Scenarios A and B.

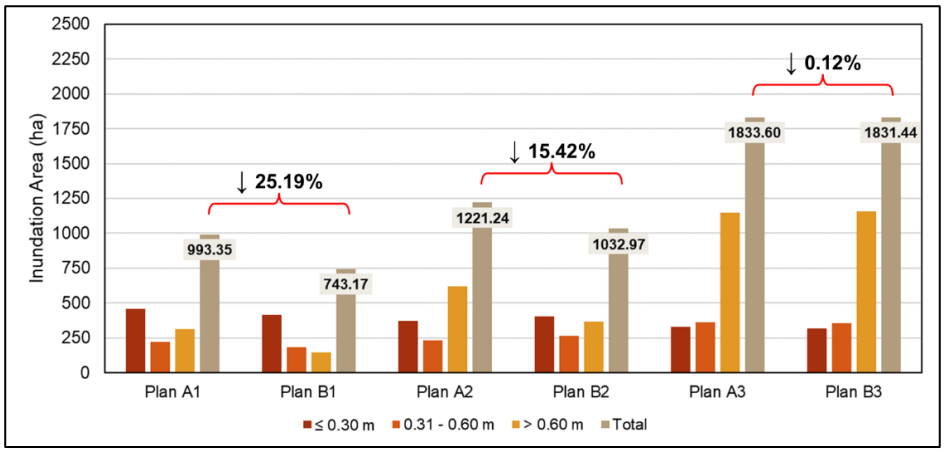



Figure 8 Comparison Between Scenario A and Scenario B Inundation Area

Additional pump locations and capacity upgrades were proposed to enhance flood management, as depicted in Figure 9. These recommendations were tailored based on inundation depth and area analysis.

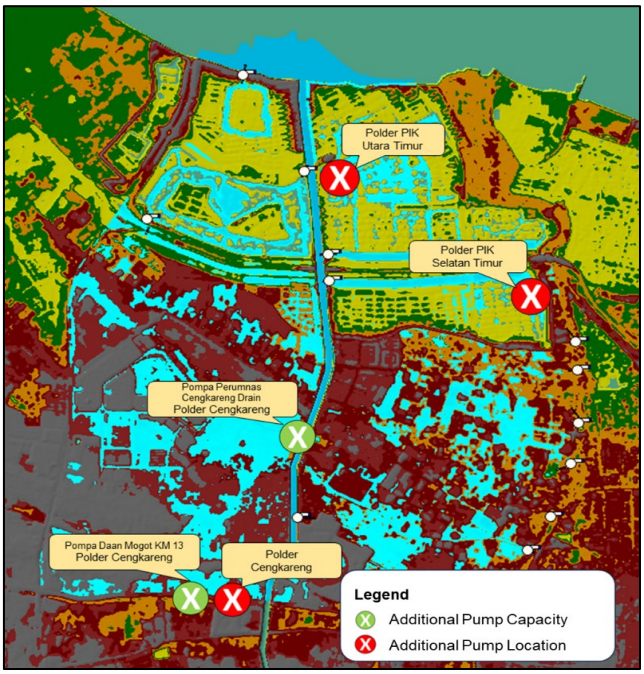


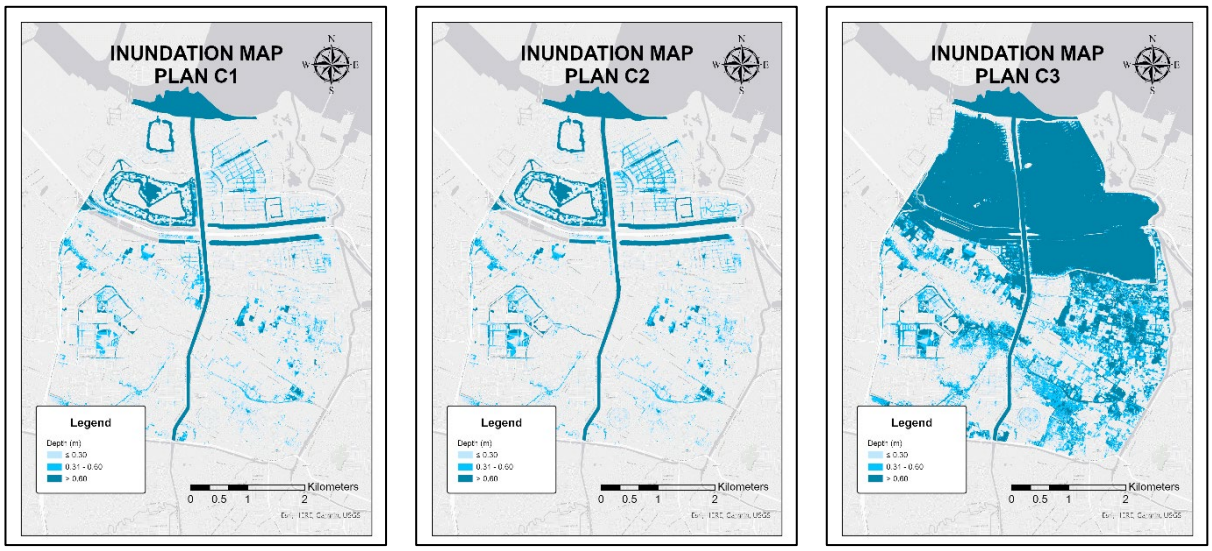

Figure 9 Recommendation on Pump Locations and Capacities

The locations were proposed by considering the inundation area and depth that needs to be managed. Depending on the depth and area, there may be an urgency for the flooding to be reduced in time or severity. Therefore, the details on the pump recommendations' locations and capacities are provided in Table 6.

Table 6 Additional Pump Locations and Capacities

| No. | Location | | Existing Capacity ($m^3s^{-1}$) | New Capacity ($m^3s^{-1}$) |
|---|---|---|---|---|
| | Polder | Pump Station | | |
| 1 | PIK Utara Timur | - | - | 2 |
| 2 | PIK Selatan Timur | - | - | 1 |
| 3 | Cengkareng | Perumnas Cengkareng Drain | 7.5 | 10 |
| 4 | Cengkareng | Daan Mogot KM 13 | 0.5 | 1 |
| 5 | Cengkareng | - | - | 1 |

Figure 10 shows the decreased inundation areas in the recommended scenarios under current and projected minimum LS conditions in 2050. However, the impact is less pronounced under maximum LS projections. Figure 11 further illustrates the comparison between Scenarios A, B, and C regarding inundation areas.




(a) (b) (c)

Figure 10 Inundation Map Comparison

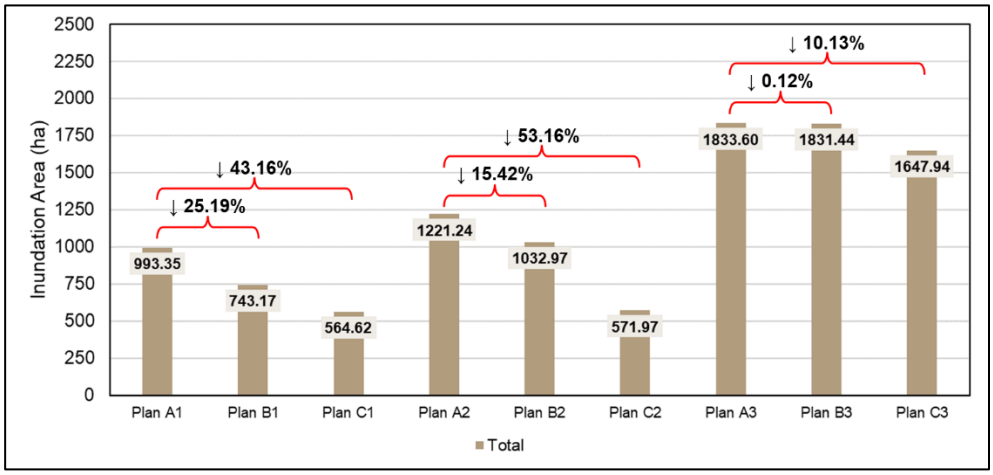



Figure 11 Comparison Between Scenario A, Scenario B, and Scenario C Inundation Area

The analysis found that the recommendations could substantially reduce inundation in various scenarios, with up to 43.16% reduction in the current condition and up to 53.16% in the 2050 scenario with minimum LS. However, the reduction was limited to 10.13% under the maximum LS in 2050. While additional infrastructure helps, it alone may not enhance coastal resilience, especially under maximum LS conditions.

Controlling LS rates is critical. This can be achieved through LS monitoring, water usage control, land use planning, and public awareness campaigns. Regular dredging of the Cengkareng Drain channel is also suggested to maintain channel capacity and ensure efficient water flow to the sea.

## 5. CONCLUSION

The current plan for the embankment on the Cengkareng Drain Estuary has effectively reduced inundation areas under current conditions. However, the projected year 2050 shows that the effectiveness will be reduced from the previous 25.19% to just 15.42% - 0.12%. This value shows a need to implement further measures to increase coastal resilience.

Three recommendations are presented in this study. First, add new pump locations and increase existing pump capacity. By implementing this recommendation, the inundation area will be reduced by 43.16% under current conditions and 53.16% to 10.13% by the projected year 2050. Second, local land subsidence should be controlled by enforcing the law and raising people's awareness of the issue's urgency. Lastly, periodic dredging is recommendeed to maintain the current channel capacity.

## 6. ACKNOWLEDGEMENT

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# IMPACT ANALYSIS OF LAND USE CHANGES ON INUNDATION MAP IN THE CILIWUNG RIVER WATERSHED

Muhammad Raihan Arkan Abiyan Zein[1, *], Evi Anggraheni[1], Dadang Muhamad Yahya[2]

[1]Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok, 16424, West Java, Indonesia
[2]Pemali-Juana River Basin Area, Directorate General of Water Resources, Ministry of Public Works, Semarang, 50246, Central Java, Indonesia

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## ABSTRACT

The rapid population growth in Indonesia's DKI Jakarta Province has escalated the demand for housing, increasing built-up land at the expense of green open spaces, known as *Ruang Terbuka Hijau* (RTH). This shift has significantly reduced the land available for water infiltration, resulting in increased runoff and flow discharge, particularly in the Ciliwung River Watershed. This research aims to map inundation in the Ciliwung River Watershed, which is attributable to land cover changes from 1990 to 2022. The study examines flood flow discharge and inundation patterns by utilizing HEC-HMS 4.10 for hydrological modeling and HEC-RAS 6.1 for 1D and 2D hydraulic models. Boundary conditions were based on recorded flood flow discharge at the Manggarai Water Gate and Katulampa Dam, combined with historical rainfall data, to represent watershed conditions accurately. Applying 1D and 2D models provides a detailed visualization of inundation changes over time. Findings reveal that identical rainfall events result in varying flood flow discharges and inundation extents due to different land covers. The Kinematic Wave routing method demonstrated high accuracy, with Nash-Sutcliffe Efficiency (NSE) and regression coefficient values of 0.93 and 0.99, respectively. The study concludes that flow discharge and inundation areas increase with the Curve Number (CN) value. Furthermore, the magnitude of rainfall return periods significantly influences discharge volumes and inundation depths, with areas experiencing 0 – 0.3 meters of flooding predominant in the Ciliwung watershed.

*Keywords*: Flow discharge; Inundation area; Kinematic wave; Land cover; Nash-Sutcliffe Efficiency (NSE)

## 1. INTRODUCTION

DKI Jakarta province, where Indonesia's capital is now currently located, is one of the world's most densely populated metropolitan areas. The 2022 statistics from the Central Bureau of Statistics and Rachim et al. (2022) report a population of 10.64 million within an area of just 662.33 km². With a population growth rate of 0.38%—higher than the previous year—the demand for housing continues to intensify. This expansion has significantly decreased green spaces and water catchment areas, exacerbating environmental challenges.

*Corresponding author's email: abiarkan10@gmail.com, Tel. +62-881-18010234
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Over the decades, a drastic decline in the city's green space has been observed. The Directorate General of Spatial Planning of the Ministry of Agrarian Affairs and Spatial Planning / National Land Agency notes a decrease from 35% in the 1970s to merely 9.9% - 14.9% in 2021, as highlighted by the former Head of the DKI Jakarta Forestry Service, Suzi Marsitawati, and the World Resources Institute (WRI) (Harahap, 2021).

This starkly contrasts the vision outlined in Article 6 Paragraph 5b of DKI Jakarta Regional Regulation Number 1 of 2012, which projects a 30% green open space area comprising 20% public and 10% private spaces (Eni, 2015). The diminishing green spaces impede rainwater infiltration, increasing surface runoff and straining the Ciliwung River Watershed.

Flooding, exacerbated by excessive surface runoff, is a frequent issue in DKI Jakarta, particularly along the riparian zones, which have been transformed into densely populated areas, diminishing their capacity to function as floodplains. The Ciliwung River, a significant watercourse spanning 119 km from Puncak, Bogor, through the Depok Region into Jakarta, with a catchment area of 328 km² (Purwanti & Pontiawaty, 2013), is often implicated in these flood events. According to the Head of Katulampa Dam, this river is a primary contributor to seasonal flooding, as evidenced by the January 1, 2020 event that recorded the highest rainfall in 24 years at Halim Perdanakusuma Air Force Base, with 377 mm/day, leading to a peak flood discharge of 3,389 m³/sec, surpassing the river's capacity of 2,357 m³/sec (Abay & Haryanto, 2021). This resulted in widespread flooding, affecting 158 urban villages in Jakarta and its environs.

This study aims to analyze the exacerbating flood situation in the Ciliwung River Watershed about land cover changes. Utilizing the Kinematic Wave routing method, hydrological and hydraulic analyses were conducted using land cover data in 1990, 1995, 2000, 2009, 2016, and 2022. This analysis aims to assess the impact of land cover alterations on flood hydrographs and the resulting inundation within the watershed.

## 2. LITERATURE STUDY

### 2.1. Floods

Floods are the inundation of water beyond its normal confines, such as from rivers, rainwater, or tidal seawater (Amalia & Wesli, 2015). In Indonesia, flooding is attributed to several interrelated factors: high-intensity rainfall, sedimentation in river channels, planning and construction errors in river channel development, improper spatial planning around watersheds, and malfunctioning watershed retention systems (Maryono, 2020; Taryana et al., 2022; Widyaiswara, 2020).

The Ciliwung Watershed, emptying into DKI Jakarta, is particularly prone to flooding, notably in its downstream urban areas. The watershed's morphology plays a significant role in this vulnerability. In the upper reaches, up to the Katulampa Dam, the watershed exhibits a dendritic (fan-like) pattern. However, towards the middle and downstream sections, the watershed narrows into a parallel formation (BPDAS Ciliwung-Citarum, 2007). According to Trisakti et al. (2008), this narrowing at the Katulampa Dam section results in significant runoff from upstream areas, accounting for about 44% of the watershed’s discharge. The transition from a dendritic to a parallel pattern also contributes to flash floods, exacerbated by the constriction of the watershed's shape.

### 2.2. Design Rainfall and Area Rainfall

The analysis of design rainfall begins with a crucial initial step, an outlier testing. The primary goal is to detect any anomalies within the collected rainfall data. This process includes examining data distributions and conducting consistency tests, which utilize probability distributions to

establish the relationship between the frequency and magnitude of extreme rainfall events (Kementerian PUPR, 2018). For this purpose, the study employs Normal Distribution, Log Pearson Type III, and Gumbel Distribution. The consistency of the data is verified using the Chi-Square and Smirnov-Kolmogorov tests, ensuring the reliability of the rainfall data for subsequent analyses.

Once the design rainfall analysis is completed, the study proceeds to calculate regional rainfall. This step is vital for understanding how rainfall varies across the study area. To accomplish this, there are three methods involved, including the arithmetic average method, the Thiessen polygon method, and the isohyet method. Given the favorable abundance of rain gauge stations within the Ciliwung watershed, the Thiessen polygon method emerges as the most suitable choice. The formula for the Thiessen polygon method is:

$$\underline{R} = \frac{A_1R_1 + A_2R_2 + A_3R_3 + \cdots + A_nR_n}{A_1 + A_2 + A_3 + \cdots + A_n} \tag{1}$$

Where $\underline{RR}$ is the regional rainfall (mm), $A_1$, $A_2$, ..., $A_n$ is the area of influence of each precipitation station on the reviewed area ($m^2$), and $R_1$, $R_2$, ..., $R_n$ Which is the rainfall at the reviewed precipitation station (mm).

### 2.3. Soil Conservation Service-Curve Number (SCS-CN) Method Design Flood

The Soil Conservation Service-Curve Number (SCS-CN) method is an empirical technique extensively utilized for estimating direct runoff from rainfall events, as outlined in Nasjono's research (2018). This method is versatile and applicable across various catchment types, such as small farms, forests, and urban areas. It is particularly effective in integrating diverse catchment characteristics into runoff calculations. The SCS-CN method is based on specific relationships between several hydrological parameters, which are computed as follows:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$
$$S = 25.4\left(\frac{1000}{CN} + 10000\right) \tag{2}$$

Where $P$ is precipitation (mm), $P_e$ is direct runoff (mm), $I_a$ is initial abstraction (mm), $S$ is maximum retention potential (mm), and $CN$ is curve number.

The SCS-CN method's efficacy lies in its simplicity and adaptability, enabling the integration of various catchment attributes into a unified runoff model. Its application in this study facilitates a nuanced understanding of runoff dynamics in the context of diverse land covers and urbanization patterns within the catchment area.

### 2.4. Hydrological Model

In this study, hydrological modeling is conducted using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). This robust tool transforms rainfall data into various hydrological components like runoff volume, direct runoff, baseflow, and channel flow. A critical component of this modeling process is the routing method, for which the Kinematic Wave method is employed.

The Kinematic Wave method is chosen based on its applicability in time series analysis and integration into semi-distributed hydrological models. This method incorporates mathematical modeling through transfer and production functions (Chow et al., 1988). Transfer functions theoretically model the response to the output from various potential inputs, while production functions transform an input into different outputs based on available data.

Key parameters within the Kinematic Wave method are numerous and complex, including channel slope, overland flow rate, channel cross-sectional area, channel roughness, and conveyance factor. Due to this complexity, certain assumptions are made in the modeling process. The Kinematic Wave method is particularly well-suited for urban areas, where such complexities are commonplace and must be accurately represented in hydrological models.

### 2.5. Nash-Sutcliffe Efficiency (NSE) Model Validation

The Nash-Sutcliffe Efficiency (NSE) test is a widely recognized method for assessing the accuracy of hydrological models. It evaluates the model's validity by comparing the observed and simulated data sets. The NSE is calculated using the following equation (Suhartanto et al., 2019; Zhao et al., 2017):

$$NSE = 1 - \frac{\Sigma_{i=1}^{n}(O_i - S_i)^2}{\Sigma_{i=1}^{n}\left(O_i - \underline{O_i}\right)^2}, -\infty < NSE \leq 1 \quad (3)$$

Where NSE is the Nash-Sutcliffe coefficient, n is the amount of data, S is the modeled flow discharge value ($m^3/s$), O is the observed flow discharge value ($m^3/s$), and $\underline{O}$ is the average observed flow discharge value ($m^3/s$). Table 1 shows the value criteria of the NSE.

Table 1. Nash-Sutcliffe Efficiency (NSE) Value Criteria

| NSE Value | Interpretation |
|---|---|
| NSE > 0,75 | Good |
| 0,36 < NSE < 0,75 | Fair |
| NSE < 0,36 | Not Satisfied |

(Motovilov et al., 1999)

This model validation step is crucial in ensuring the reliability and accuracy of the hydrological model used in the study. The NSE test provides a quantitative measure of the model's predictive power, allowing for an objective evaluation of its performance against observed data.

### 2.6. Hydraulics Model

Hydraulic modeling is a critical aspect of understanding river flow dynamics. As Potter et al. (2011) describe, channel flow is the movement of water particles, which can be classified based on their average velocities. In river hydraulics, water flow is typically categorized into four distinct types: steady flow, unsteady flow, uniform flow, and non-uniform flow. Each type offers unique insights into the behavior of water in natural and engineered channels. Hydrologic Engineering Center's River Analysis System (HEC-RAS) software is employed for hydraulic modeling in this study. HEC-RAS provides the tools to conduct both one-dimensional (1D) and two-dimensional (2D) hydraulic analyses.

In the 1D Hydraulic Modeling, the cross-section and channel geometry of the river were involved. 1D modeling is essential for understanding the flow patterns and velocities along the river channel, providing a detailed look at how water moves through and interacts with the channel.

On the other hand, in the 2D Hydraulic Modeling, the 2D component of HEC-RAS, particularly the RAS Mapper, is used to generate inundation maps. These maps are crucial for visualizing and analyzing the extent of inundation resulting from varying flow discharges, especially the impacts of land cover changes within the Ciliwung watershed.

Through the combination of 1D and 2D modeling, this study aims to understand the hydraulics within the Ciliwung watershed comprehensively. This approach enables the exploration of how land cover changes influence river flow dynamics and the consequent inundation patterns, which are critical for effective flood management and planning in the region.

## 3. METHODS

### 3.1. Research Flow Chart

The methodology of this study is systematically outlined in a research flow chart, depicted in Figure 1. This flow chart visually represents the sequential steps in the research process, from the initial data collection phase to the final analysis and interpretation of results.

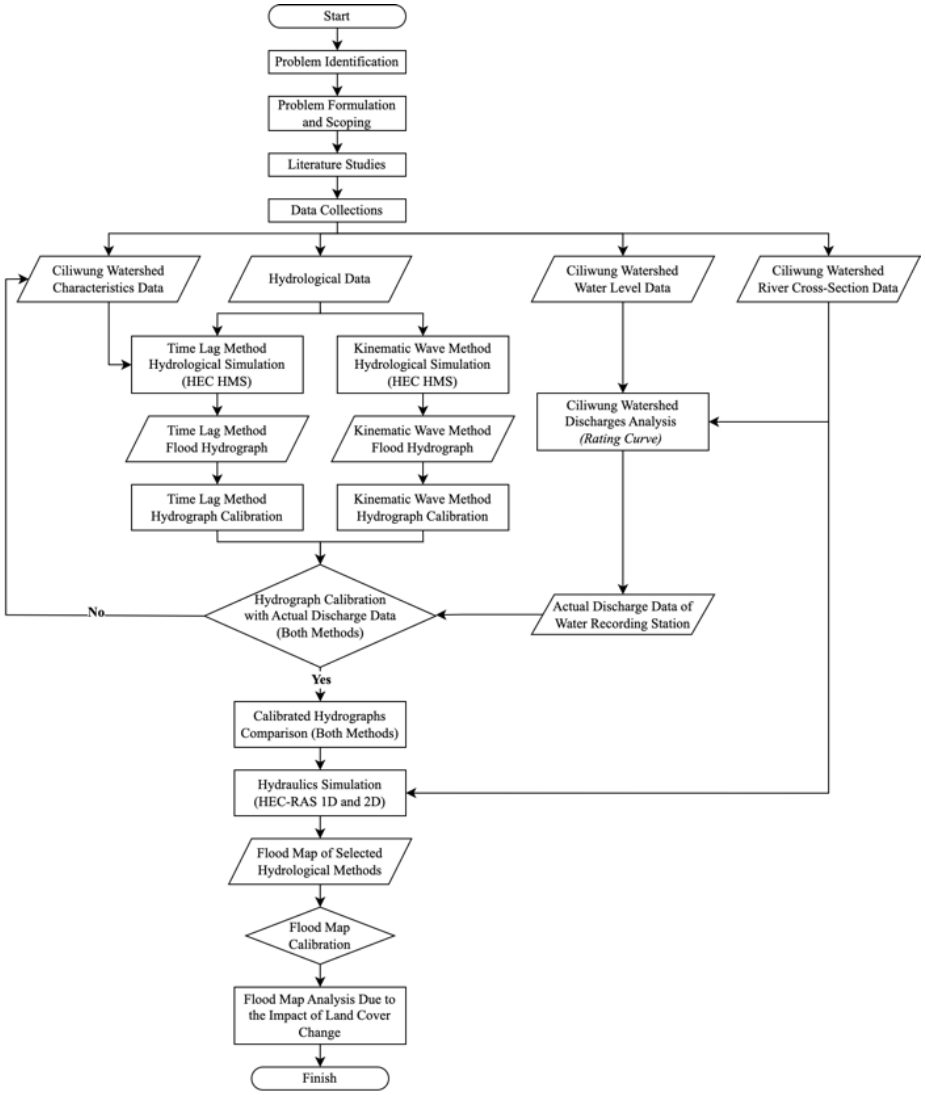



Figure 1 Research Flow Diagram

The flow chart begins with collecting relevant hydrological and hydraulic data, including rainfall records, river flow data, and land cover changes. Following data collection, the study analyzes this data using the methodologies outlined in the previous sections, such as the SCS-CN method for runoff calculation and HEC-RAS for hydraulic modeling.

Subsequent steps in the flow chart illustrate the model calibration and validation process, using techniques like the Nash-Sutcliffe Efficiency test to ensure the accuracy and reliability of the models. The final stages of the research involve applying these models to simulate various flood scenarios within the Ciliwung River Watershed, analyzing the impacts of land cover changes, and formulating recommendations based on the findings.

### 3.2. Research Location

This study focuses on the Ciliwung Watershed, an essential hydrological feature spanning several key regions in Indonesia. The research comprehensively covers the entire watershed stretch, starting from its upstream areas, extending through its middle course, and concluding at its downstream termination.

The upstream portion of the Ciliwung watershed originates at Telaga Warna Pangrango, situated at the base of Mount Pangrango in the Puncak region of Bogor. This area is critical as it sets the initial river flow conditions and characteristics.

Progressing downstream, the watershed traverses through the Depok area. This section represents the middle part of the watershed, where significant changes in land use and urbanization patterns are observed, influencing the river's hydrological behavior.

The study extends to the downstream end of the watershed, concluding at the Manggarai Sluice Gate in East Jakarta. This point marks the final convergence of the watershed's flow before integrating into Jakarta's larger hydrological system.

The selection of the Ciliwung watershed as the research location is strategic, encompassing diverse ecological, urban, and geographical features. This comprehensive coverage allows an in-depth analysis of the watershed's hydrological dynamics, from its natural mountainous origins to its heavily urbanized lower reaches.

### 3.3. Data Sources

The research employs a comprehensive data collection approach, utilizing spatial, hydrological, and hydraulic data to facilitate an in-depth analysis of the Ciliwung watershed.

a) Spatial Data.
   Digital Elevation Model (DEM) and Landsat-8 Images: These datasets, spanning the years 1990, 1995, 2000, 2009, 2016, and 2022, are crucial for creating detailed land cover data. This data aids in the calculation of rainfall-runoff relationships and in determining flood plans using the SCS-CN method. The DEM data is also instrumental in delineating the Ciliwung watershed for HEC-HMS modeling and forming the terrain model for HEC-RAS 2D.
b) Hydrological Data.
   Daily Rainfall Data: Covering a 23-year period from 1998 to 2021, this dataset is essential for understanding precipitation patterns and trends within the watershed.
   Flow Rating Curve Data and Hourly Water Level Data: Sourced from Manggarai and Katulampa, these data sets are used to calculate flow discharge values. They play a vital role in validating the modeled discharge using the Nash-Sutcliffe Efficiency (NSE) and Linear Regression methods.

c) Hydraulic Data:
Cross-Section Data: Obtained at various points along the Ciliwung River, this data is provided by BBWS Ciliwung-Cisadane and BMKG. Constructing accurate hydraulic models and understanding the river's flow dynamics is essential.

This structured approach to data collection ensures a comprehensive understanding of the Ciliwung watershed's hydrological and hydraulic behaviors. Integrating spatial, hydrological, and hydraulic data enables a multidimensional analysis crucial for accurate flood modeling and watershed management.

## 4. RESULTS AND DISCUSSION

### 4.1. Land Cover

The study's analysis of land cover within the Ciliwung watershed is crucial for understanding the impact of land use changes on hydrological behaviors. The Watershed Delineation was performed utilizing ArcGIS software, identifing its boundary and classify its 14 sub-watersheds. This delineation is essential for targeted analysis within each subwatershed. The resulting map of the Ciliwung watershed and its sub-watersheds is illustrated in Figure 2.

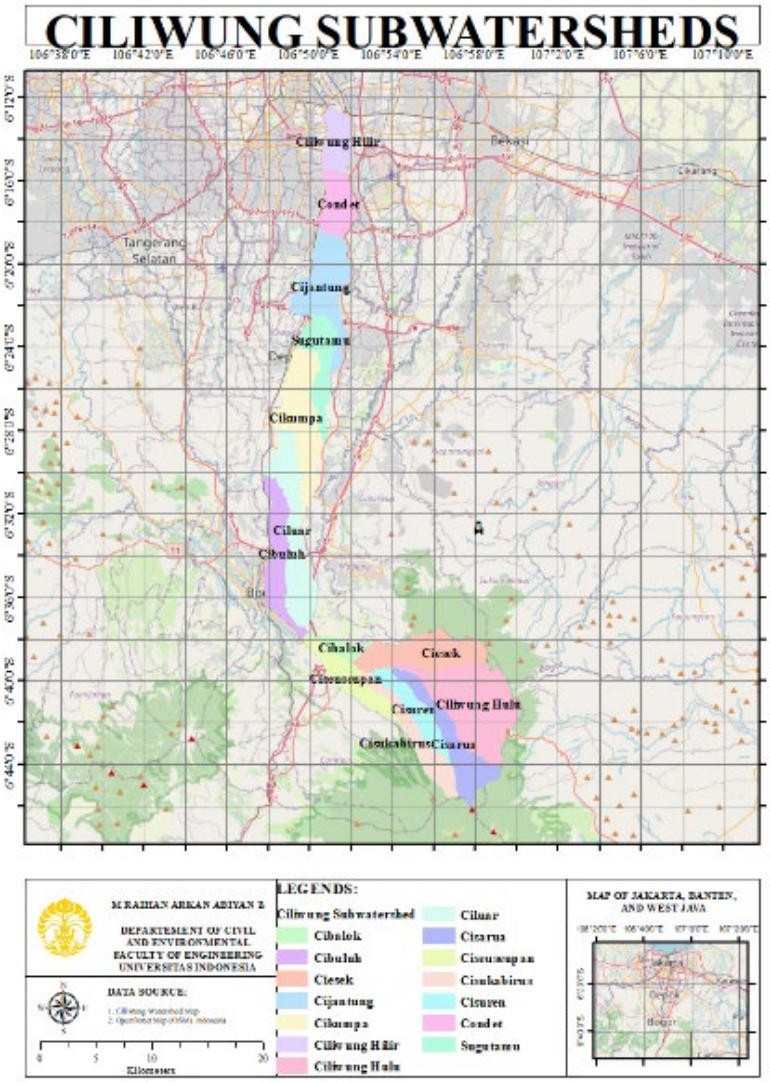



Figure 2. Ciliwung Sub Watershed

Land cover classification for each review year was determined using the image classification method, which enables the categorization of various land cover types within the watershed. Figure 3 depicts the changes in land cover over the years, visually representing these shifts.

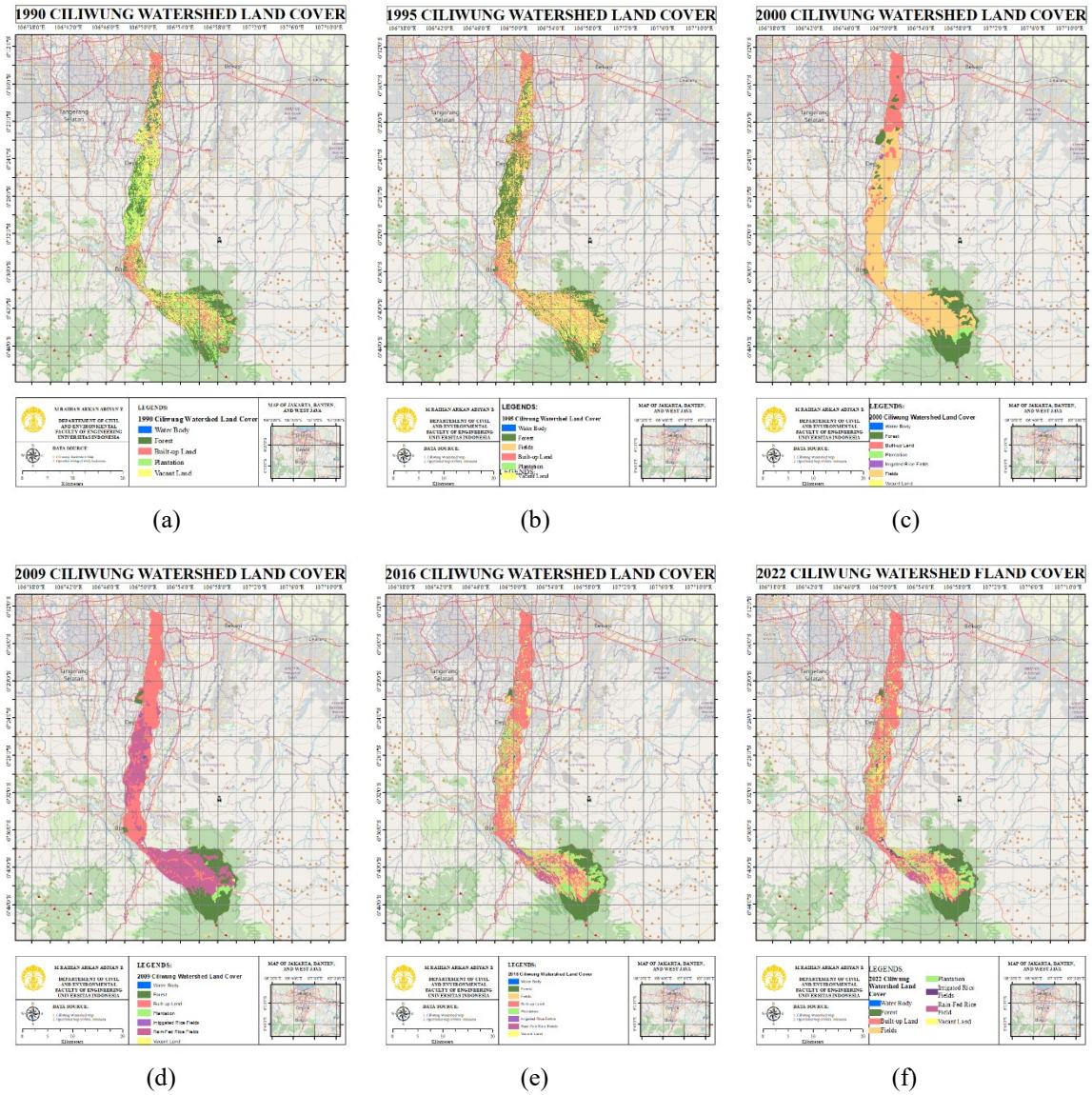



Figure 3. Ciliwung Watershed Land Cover Changes (a) Year 1990, (b) Year 1995, (c) Year 2000, (d) Year 2009, (e) Year 2016, and (f) Year 2022

The analysis of changes in land cover reveals a noteworthy trend, particularly in the substantial increase of "built-up land." As illustrated in Figure 4, there has been a remarkable surge both in the area and the percentage of built-up land, surging from 20.72% (equivalent to 67.97 km²) in 1990 to a substantial 43.76% (equivalent to 136.88 km²) in 2022. This significant transformation reflects as a clear indicator of the rapid urbanization occurring within the watershed and raises important questions about its potential implications on water management and flood risk mitigation.

The results highlight a critical shift in the Ciliwung watershed's land cover over the past three decades, underlining the need for updated water management strategies to adapt to these changes. The increase in built-up areas suggests a decrease in permeable surfaces, likely contributing to altered hydrological dynamics and increased flood risks in the region.

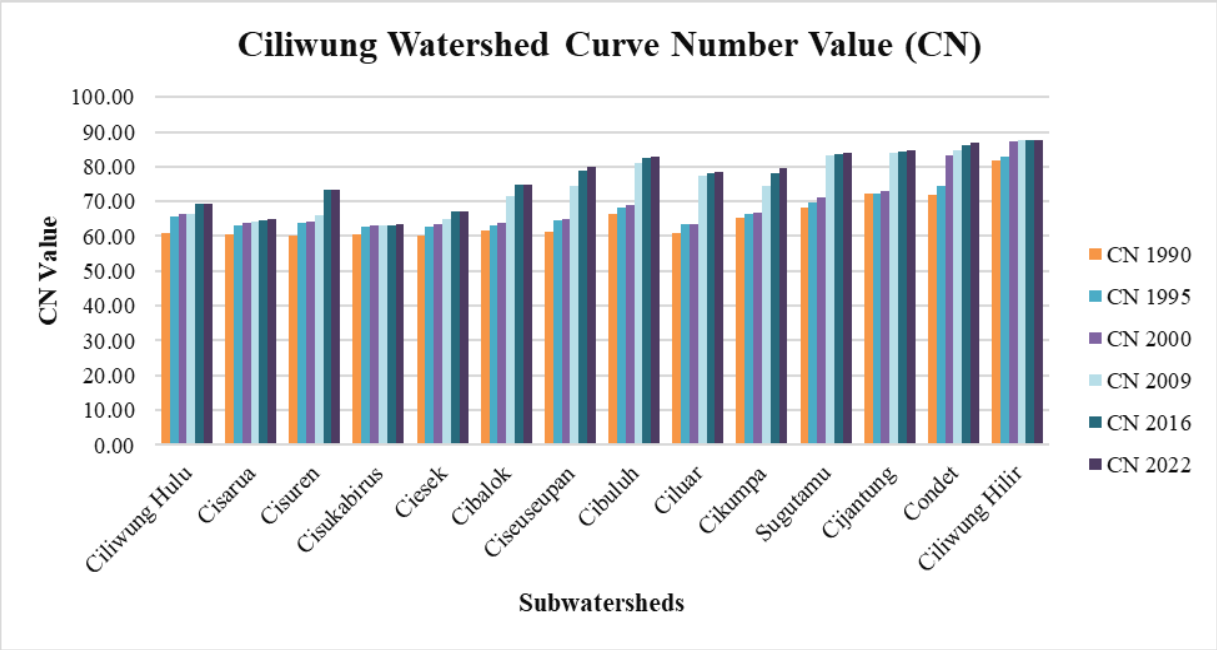



Figure 4. Ciliwung Watershed Curve Number (CN) Changes

### 4.2. Design Rainfall

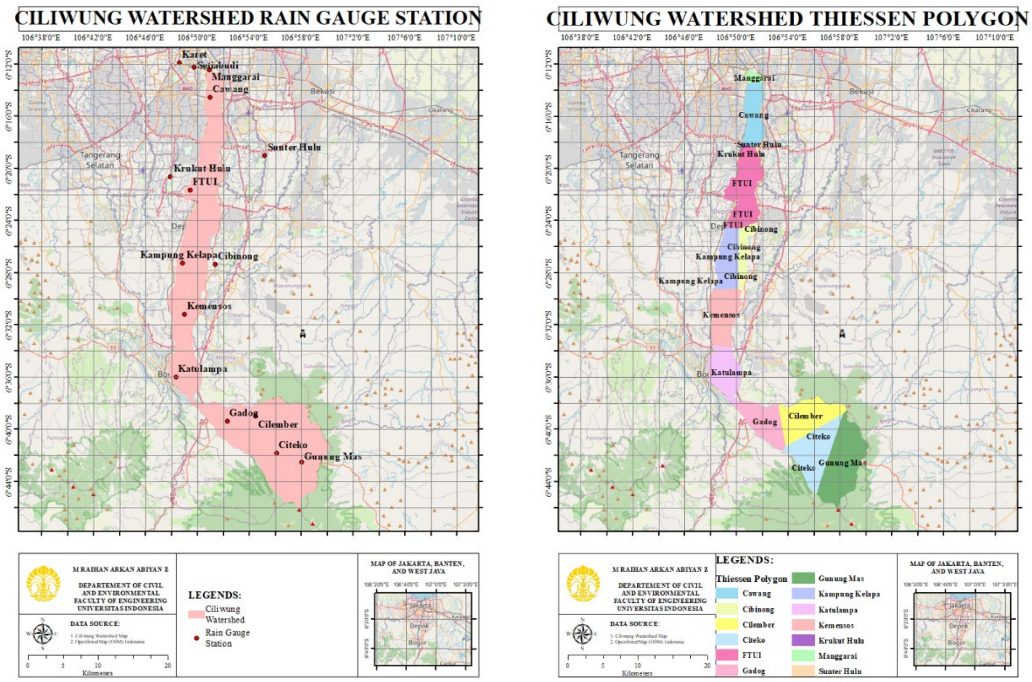
Determining design rainfall involved rigorous testing of rainfall data, particularly for the initial planning of 50-year and 25-year rain return periods. This analysis made the Log Pearson Type III distribution method the most suitable for our design rainfall calculations, as outlined in Table 2. This choice was based on successfully fulfilling all test criteria, making it the preferred method in our study.

Table 2 Design Rainfall Value of Every Rain Gauge Station in Ciliwung Watershed

| Precipitation Stations | XTr 25-year (mm) | XTr 50-year (mm) |
|---|---|---|
| Manggarai | 208.401 | 224.166 |
| Karet | 180.873 | 204.178 |
| Setiabudi Timur | 247.822 | 287.182 |
| Cawang | 194.765 | 203.103 |
| Krukut Hulu | 164.228 | 170.968 |
| Sunter Hulu | 285.330 | 342.699 |
| Kemensos | 72.025 | 73.650 |
| Kampung Kelapa | 157.035 | 157.804 |
| FTUI | 166.143 | 176.389 |
| Cibinong | 153.923 | 164.653 |
| Cilember | 151.413 | 159.632 |
| Gadog | 162.938 | 171.203 |
| Citeko | 199.527 | 223.882 |
| Katulampa | 155.236 | 161.711 |
| Gunun Mas | 164.724 | 172.068 |

Following the design rainfall analysis, regional rainfall was assessed using the Thiessen polygon method. This method facilitated the division of affected areas within the Ciliwung watershed based on the proximity and influence of each rain gauge station. Figure 5 illustrates the locations

of these stations and the corresponding Thiessen polygons, providing a spatial understanding of their influence on the watershed's rainfall distribution.



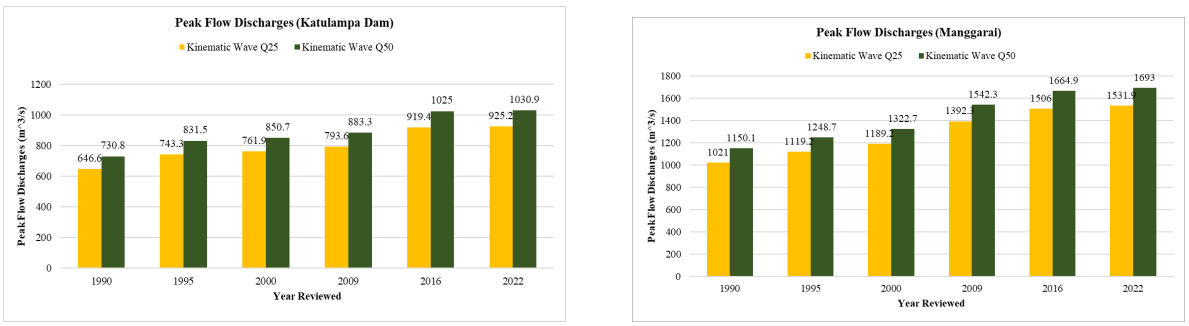

(a) (b)

Figure 5. Ciliwung Watershed (a) Rain Gauge Station Location and (b) Thiessen Polygon

The analysis of design rainfall and regional rainfall distribution plays a crucial role in understanding the hydrological dynamics of the Ciliwung watershed. By identifying the rain return periods and assessing the spatial influence of rainfall, this section lays the groundwork for subsequent flood modeling and water management strategies.

### 4.3. Hydrological Model of HEC-HMS

The hydrological modeling conducted using HEC-HMS reveals distinct characteristics in the flood hydrographs, influenced by various scenarios. A notable observation from this analysis is the increase in peak discharge at both the Katulampa Dam (junction-5) and the Manggarai Dam (outlet) for the 25-year and 50-year return periods, spanning from 1990 to 2022. This trend, depicted in Figure 6 and detailed in Table 3, highlights the region's evolving nature of flood risks.




(a) (b)

Figure 6. Graph of Peak Flow Discharges in Ciliwung Watershed (a) In Katulampa Dam and (b) In Manggarai

Despite consistent rainfall values, the differences in discharge for each review year can be attributed to land cover changes and variations in Curve Number (CN) values. These changes affect surface runoff from the land, which subsequently influences flow discharge.

Table 3 Peak Flow Discharges of the Year Reviewed in Katulampa and Manggarai Viewpoint

| Year | Peak Flow Discharges | | | |
|---|---|---|---|---|
| | 25-Year Return Period | | 50-Year Return Period | |
| | ***Junction*-5 Katulampa ($m^3/s$)** | ***Outlet* Manggarai ($m^3/s$)** | ***Junction*-5 Katulampa ($m^3/s$)** | ***Outlet* Manggarai ($m^3/s$)** |
| 1990 | 646.6 | 1021.0 | 730.8 | 1150.1 |
| 1995 | 743.3 | 1119.2 | 831.5 | 1248.7 |
| 2000 | 761.9 | 1189.2 | 850.7 | 1322.7 |
| 2009 | 793.6 | 1392.3 | 883.3 | 1542.3 |
| 2016 | 919.4 | 1506.0 | 1025.0 | 1664.9 |
| 2022 | 925.2 | 1531.9 | 1030.9 | 1693.0 |

In the HEC-HMS hydrological modeling, the Kinematic Wave routing method was employed. This method was chosen due to its ability to consider complex hydrological parameters comprehensively, including the celerity index, channel geometry, slope, and Manning's coefficient. Utilizing the Kinematic Wave method ensures a detailed and accurate representation of flow dynamics within the Ciliwung watershed, capturing the nuances of hydrological changes over time.

### 4.4. Nash-Sutcliffe Efficiency (NSE) and Regression

Data calibration in this study was crucial for enhancing the alignment between observed and modeled hydrological responses. We employed the Nash-Sutcliffe Efficiency (NSE) and linear regression methods to validate the modeled flow discharge impacted by land cover changes. The observed discharge data selected for comparison was based on significant rainfall events on four specific dates in 2020, as recorded by the Manggarai AWLR (see Table 4).

Table 4 Comparison of Observed Modelled Peak Flow Discharge at Manggarai Viewpoint

| Dates | Peak Time | Q Observed ($m^3/s$) | Q Modelled ($m^3/s$) |
|---|---|---|---|
| January 1, 2020 | 12:00 | 917.57 | 767.90 |
| February 8, 2020 | 23:00 | 432.84 | 443.10 |
| February 23, 2020 | 23:00 | 453.64 | 470.20 |
| February 25, 2020 | 23:00 | 667.16 | 414.20 |

The initial modeling results showed significant deviations between the observed and modeled discharges. The NSE coefficient and linear regression values were notably distant from the ideal 1 (E = 1; R = 1), indicating the need for model recalibration.

Consequently, we calibrated the CN value of built-up land from 85 to 88 and included additional review dates in 2020. This recalibration aimed to achieve a more accurate match between the modeled and observed data, as shown in Table 5.

Table 5 Comparison of Calibrated Observed and Modelled Peak Flow Discharge at Manggarai Viewpoint

| Dates | Peak Time | Q Observed ($m^3/s$) | Q Modelled ($m^3/s$) |
|---|---|---|---|
| January 1, 2020 | 12:00 | 917.57 | 830.50 |
| February 8, 2020 | 23:00 | 432.84 | 401.20 |
| February 23, 2020 | 23:00 | 453.64 | 437.10 |
| February 25, 2020 | 23:00 | 667.16 | 619.50 |
| March 1, 2020 | 06:00 | 399.05 | 342.70 |
| March 27, 2020 | 06:00 | 520.32 | 519.70 |

Post-calibration, the modeled discharges were noticeably closer to the observed values, achieving a more accurate NSE value of 0.93 using the Kinematic Wave method (see Table 6).

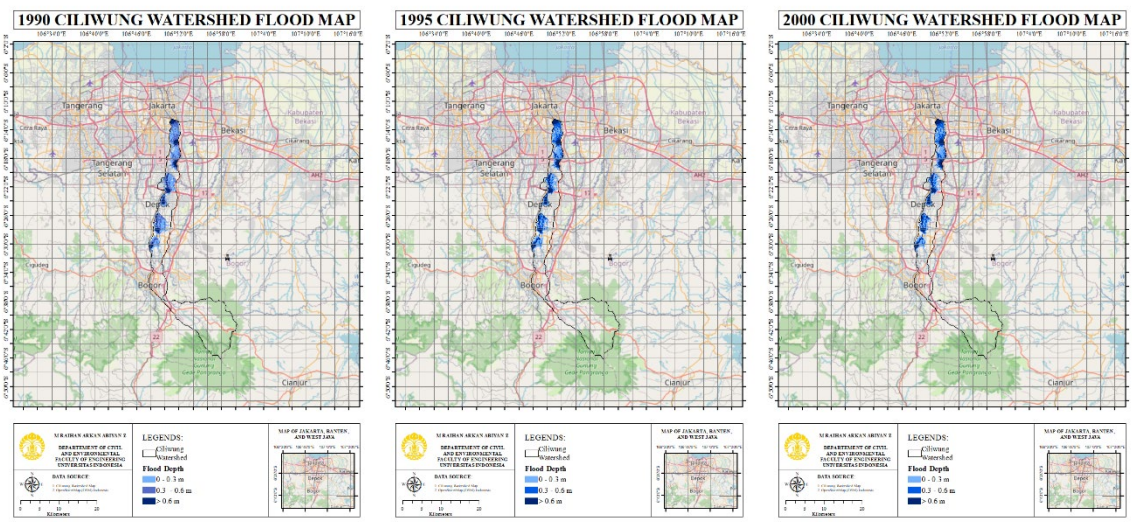
Table 6 Comparison of NSE and Regression Coefficient

| Method | Before Calibration | | Calibrated | |
|---|---|---|---|---|
| | NSE | Regression | NSE | Regression |
| Kinematic Wave | 0.43 | 0.82 | 0.93 | 0.99 |

The improved NSE value of 0.93 and regression coefficient of 0.99 post-calibration indicate the effectiveness of the Kinematic Wave method in hydrological modeling. With its complex parameterization, this method results in outputs that closely represent real-world conditions, demonstrating its suitability in hydraulic modeling.

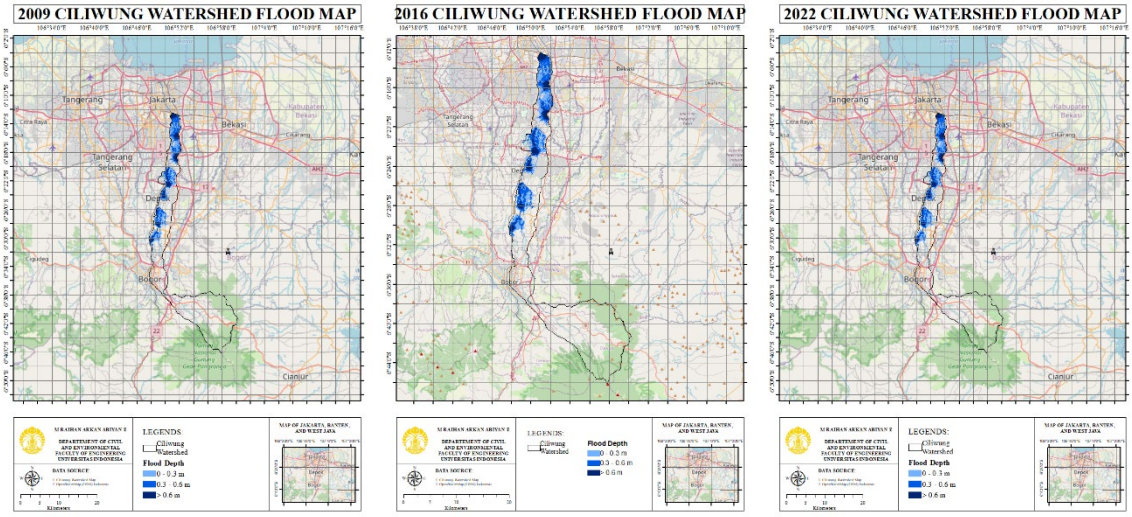
### 4.5. Hydraulics Model of HEC-RAS

This section discusses the hydraulic modeling results using HEC-RAS, complemented by RAS Mapper, for visualizing inundation in the Ciliwung watershed. The model relies on discharge data from the HEC-HMS Kinematic Wave routing method, focusing on a 50-year rainfall return period (Q50) scenario. The focal point of the analysis lies in the creation of detailed inundation maps by HEC-RAS, utilizing Digital Elevation Model (DEM) data. These inundation maps, showcased in Figure 7, offer a visual representation of flooding patterns across the watershed at various time points.




(a) (b) (c)

Figure 7. Ciliwung Watershed Flood Area Changes (a) 1990, (b) 1995, (c) 2000




(d) (e) (f)

Figure 7. Ciliwung Watershed Flood Area Changes (d) 2009, (e) 2016, and (f) 2022

Flood Depth and Area Changes: Table 7 detailing the inundation areas categorized by different flood depths from 1990 to 2022 presents the changes in flood depth and the inundation area over the years. These changes highlight the evolving nature of flood risks within the watershed.

Table 7 Changes of Flood Depth and Flood Area of Ciliwung Watersheds

| Scenarios | Inundation Area ($km^2$) | | | Total Area ($km^2$) |
|---|---|---|---|---|
| | Depth of 0 – 0.3 (m) | Depth of 0.3 – 0.6 (m) | Depth of > 0.6 (m) | |
| 1990 Q50 | 22.229 | 18.163 | 11.156 | 51.548 |
| 1995 Q50 | 23.221 | 18.769 | 11.773 | 53.763 |
| 2000 Q50 | 24.466 | 19.238 | 12.295 | 56.0 |
| 2009 Q50 | 27.092 | 25.768 | 12.672 | 65.532 |
| 2016 Q50 | 28.689 | 27.380 | 13.634 | 69.703 |
| 2022 Q50 | 28.935 | 27.399 | 14.114 | 70.449 |

The results of the flood area trend analysis in Figure 8, showing a graph of the total flood area from 1990 to 2022, emphasizes the increasing trend in inundation. Notably, the inundation area expanded from 51.548 $km^2$ in 1990 to 70.449 $km^2$ in 2022.

The observed increase in flood discharge and corresponding inundation areas from 1990 to 2022 is significant. It indicates that changes in flood flow discharge are pivotal in exacerbating inundation within the watershed. The influence of land cover changes, particularly the Curve Number (CN) parameter, is evident. The progressive increase in built-up land and reduction in green spaces, especially in the urban areas of Central to Lower Ciliwung, exacerbates flooding. Flat topography also contributes to the extent of inundation in these areas.

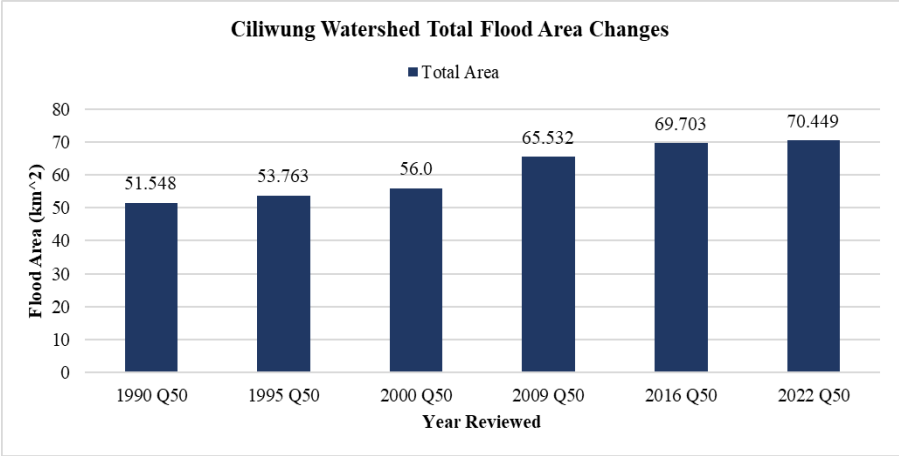



Figure 8. Graph of Total Flood Area in Ciliwung Watersheds from 1990 to 2022

For the historical inundation mapping, a close correlation was observed by comparing the inundation points from this study (Figure 7) with historical flood data for the Jakarta area (Figure 9). This comparison underscores the study's relevance and accuracy in capturing flood patterns in the Ciliwung watershed.

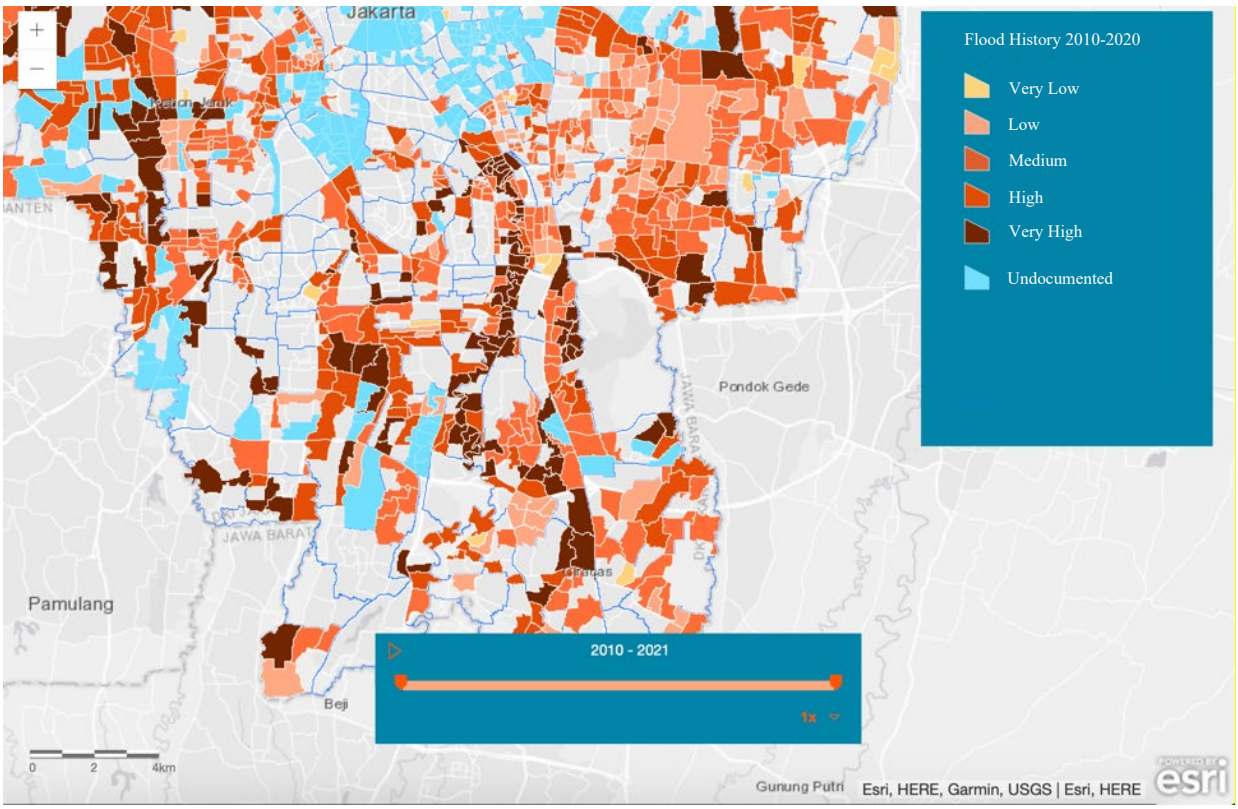



Figure 9. Historical Inundation Map of Jakarta Area

## 5. CONCLUSION

This study comprehensively analyzed the impact of land cover changes in the Ciliwung watershed from 1990 to 2022. Notable findings include a significant transformation in the land cover, particularly in the built-up land, which exhibited an increase of 23.04%. Concurrently, there was

a marked decrease in green open spaces by 35.85%. These changes directly influenced the hydrological dynamics of the watershed. The flow discharge model, validated using the Nash-Sutcliffe Efficiency (NSE) and Linear Regression methods, demonstrated high accuracy with NSE and regression values of 0.93 and 0.99, respectively. These results were achieved using the Kinematic Wave method, validating the model's effectiveness in simulating flood scenarios.

There are two key observations found in this the study. Firstly, a progressive increase in the depth and area of inundation from 1990 to 2022 is linked to the rising flood flow discharge each year. This trend is attributed to the ongoing land cover changes within the watershed. Secondly, the inundation predominantly affects the middle to downstream areas of the Ciliwung watershed. The extent of inundation escalated from 51.548 km² in 1990 to 70.449 km² in 2022. Most inundation occurred at depths ranging from 0 to 0.3 meters.

Overall, the study underscores the significant impact of urbanization and land cover changes on the hydrological behavior of the Ciliwung watershed. The increasing trend in built-up areas, coupled with the reduction in green spaces, has led to heightened flood risks, particularly in the more urbanized downstream segments of the watershed. These findings highlight the need for sustainable urban planning and effective water management strategies to mitigate future flood risks in the region.

## 6. ACKNOWLEDGEMENT

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# SEASONAL VARIABILITY ON MICROPLASTIC POLUTIONS IN WATER AND SEDIMENT OF CILIWUNG RIVER

Hefty Clarissa Wilyalodia[1, *], Elgrytha Victoria Tybeyuliana[1], Alloysius Pamurda Dhika Mahendra[1], Mochamad Adhiraga Pratama[1], Suphia Rahmawati[2], Joni Aldila Fajri[2], Setyo Sarwanto Mursidik[1]

[1]Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia
[2]Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta, Indonesia

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## ABSTRACT

Microplastics, recognized as emerging contaminants, have been detected in numerous rivers globally. This study focuses on the Ciliwung River in Jakarta, examining the influence of seasonal variations—specifically the rainy and dry seasons—on microplastics' concentration, types, and colors. Sampling was conducted during November 2022 (dry season) and March 2023 (wet season) using a plankton net for water (10 liters) and an Ekman grab sampler for sediment (400 mililiters). Microplastic abundance was analyzed following the National Oceanic and Atmospheric Administration (NOAA) adaptation method, and their material characteristics were identified using Fourier Transform Infrared Spectroscopy (FTIR) testing. Results revealed a notable seasonal impact: in the dry season, average microplastic abundance was 530 particles/liter in water and 859 particles/100 grams in sediment, whereas, in the wet season, these figures rose to 1,111 particles/ liter and 1,583 particles/100 grams, respectively. Fragments were the predominant type of microplastics, and black was the dominant color in both seasons. This consistency suggests similar sources and activities contributing year-round to microplastic pollution in the Ciliwung River.

*Keywords*: Microplastics; Freshwater; Sediment; Ciliwung river; Rainfall

## 1. INTRODUCTION

Microplastics, defined as plastic particles smaller than 5 mm in diameter (Mauludy et al., 2019), have emerged as significant environmental pollutants. These particles originate from plastic waste, which undergoes physical, chemical, and biological processes to form microplastics (Galgani, 2015). Despite being resilient to natural or biological decomposition in aquatic environments, plastics degrade into smaller particles due to UV radiation and water flow. The characteristics of microplastics are diverse and analyzed based on size, shape, color, and polymer type (Wijaya & Trihadiningrum, 2019).

Microplastics pose significant threats to both aquatic biota and human health. Their small size enables penetration into tissues and cells, potentially causing various health issues (Jung et al., 2022). Microplastics are ubiquitous in the environment and are considered emerging contaminants worldwide (Wei et al., 2022). Microplastics consumed by aquatic organisms can lead to organ damage, reduced growth rates, and hormonal imbalances (Wright et al., 2013; Hollman et al., 2013). Microplastics in human body can cause inflammation, disrupt intestinal

*Corresponding author's email: heftyclarissaw@gmail.com, Tel. +62-812-88178-2982
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microbiota, decrease fertility, and carry harmful pathogens (Faujiah et al., 2022). Microplastics also impact the ecological balance by affecting microalgae and adsorbing heavy metals like Hg, Cu, Pb, Cr, Cd, and Zn (Zhang et al., 2022; Oz et al., 2019).

Sources of microplastics are categorized as in two main types: the primary and secondary. Primary microplastics are the plastics particles that are directly produced as small particles, such as beauty and cleaning products, resin powders, pellets used as animal feed, and plastic production remnants (Ariskha, 2019). On the other hand, the secondary microplastics are oginated from the degradation of larger plastics after undergoing processes like environmental photodegradation and other forms of waste decay, such as the plastic fragments from discarded plastic bags and fishing nets (Eriksen et al., 2014). Their presence in the environment is largely due to human activities and land use patterns near water bodies (Jin et al., 2022).

The discovery of microplastics in aquatic ecosystems was first made in ocean settings, where these pollutants originated from land-based sources. Rivers serve as vital channels, playing a crucial role in transporting microplastics from land to the sea, aiding their movement through estuaries. This process is responsible for a significant proportion, ranging from 88% to 95%, of microplastics discovered in estuaries and ultimately making their way into the ocean (Schmidt et al., 2017). Microplastics are commonly found in both aquatic environments and sediments, although their abundance may vary. In general, sediments contain higher levels of microplastics than the water column because they are transported and settle at a slower rate in sedimentary layers (Van Cauwenberghe et al., 2013). Microplastics in river water degrade at a far slower rate than in coastal locations, mainly because the water absorbs ultraviolet (UV) radiation, which is a crucial element in plastic decomposition (Meng et al., 2020).

Microplastic pollution is a global concern, with reports from various countries. An investigation into microplastics in the Winongo River, Yogyakarta, Indonesia, yielded 60 microplastic particles accumulated in nine fish samples collected directly from the river. Water samples were also analyzed in the Kapuas River through identification at six collection sites; the findings of which revealed an abundance of 943.3 particles/liter (Sugandi et al., 2021). Sei Sikambing River in Medan is teeming with microplastics, measuring 23.2 particles per 100 grams of dried sediment (Hasibuan et al., 2020).

The presence of microplastics in other nations is confirmed by the identification of 53.8 ± 140.7 particles/$m^3$ in the Tien River in Vietnam (Kieu-Le et al., 2023). Microplastic abundance is observed on the surface of the Qing River not only in Vietnam but also in Beijing. A correlation was determined between the average microplastic abundance before and after rainfall in the Qing River through research. Before precipitation occurred, surface water samples exhibited a particle abundance ranging from 95.24 to 3714.29 particles/$m^3$, with an average of 1164.11 particles/$m^2$. The average abundance of microplastics decreased to 1037.04 particles/$m^3$ following precipitation, with a range of 200 to 4095.24 particles/$m^3$ (Wei et al., 2022). Sediments also contain microplastics as a result of gravitational attraction; microplastics that have densities exceeding those of water will descend and accumulate in sediments (Alomar et al., 2016). In a similar vein, the abundance of microplastics in the sediment of the Yulong River in Guilin, Southwest China, varies between 247 and 1708 particles per kilogram of sediment (Shu et al., 2023).

The entry of microplastics into marine ecosystems is determined by three factors: transport facilitated by wind, movement in rivers, and human activities in marine and coastal areas (Alomar et al., 2016). Seasons have a significant impact on wind and river flow; Indonesia's meteorological characteristics are profoundly influenced by monsoon climatic conditions due to its proximity to the equator (Susilokarti et al., 2015). Specific levels of precipitation may contribute to elevated levels of pollutants in rivers as a result of surface discharge into these

aquatic environments. Precipitation has a substantial impact on the escalation of pollution indices in rivers, which are indicative of physical, chemical, and biological aspects of water quality (Nurjanah, 2018). Although precipitation may contribute to pollution burdens, it also possesses the capacity to reduce the concentration of contaminants, such as microplastics, in surface water. Furthermore, precipitation has the potential to expedite the movement of microplastics downstream by increasing water velocity (Wei et al., 2022).

In Indonesia, the Ciliwung River is particularly interesting due to its role in providing clean water to Jakarta's population as well as its pollution issues (Mahendra, 2023). As a consequence of its importance as a source of clean water and its traversal through densely populated settlement, residential, and slum areas, this study aims to investigate the presence and seasonal variation of microplastic pollution in the Ciliwung River and examine the effect of rainfall on microplastic abundance in both water and sediments.

## 2. METHODS

### 2.1. Ciliwung River

The Ciliwung River, a significant water body in the region, is located geographically between 6°05' and 6°50' South Latitude and 106°40' and 107°00' East Longitude. The river's source is Mount Telaga Mandalawangi in the Bogor Regency, and it flows into Jakarta Bay, covering a journey of approximately 117 km. With a basin area of about 347 km², the Ciliwung River stretches across the West Java Province and DKI Jakarta. In West Java, it encompasses Bogor Regency, Bogor City, and Depok City, representing the upper and middle sections of the basin. The basin's lower part falls within DKI Jakarta's boundaries (Hasibuan, 2017; Yudo & Said, 2018).

As the largest of the 13 river systems in Jakarta, the Ciliwung River exhibits a discharge range from 0.1 to 112.2 m³/second and flow velocities between 0.1 and 2.7 m/second. Its hydrological characteristics include varying depths and widths of the wet cross-section, significantly influencing the water-carrying capacity. The river's depth ranges from 0.1 to 3.2 meters, while its width spans 1.3 to 40.5 meters. Additionally, based on arta Environmental Agency in 2021, water temperature in the Ciliwung River fluctuates up to 10°C, typically between 24.5°C and 34.5°C.

The environmental state of the Ciliwung River is a matter of concern. The Jakarta Environmental Agency reported that 61% of Jakarta's rivers were heavily polluted as of 2017, a significant increase from 32% in 2014. Particularly, the Ciliwung River, assessed at 24 sampling points, was classified as heavily polluted (Syarifa, 2019). Around 80% of this pollution is attributed to household or domestic waste. In 2012. the Ministry of Environment and Forestry identified 108 waste accumulation points along the river's course. The Ciliwung River is widely utilized for various purposes by communities, including agriculture and fisheries, as a source of drinking water raw materials, and for various household activities such as bathing, washing, and sanitation. However, the water quality of the Ciliwung River has deteriorated due to contamination from waste (Anggeraeni et al., 2020). The sources of pollution in the Ciliwung River include domestic, industrial, agricultural, and livestock waste (Yudo & Said, 2018).

### 2.2. Sampling Location and Time

This study's water and sediment samples were meticulously collected from seven environmental water quality monitoring points along the Ciliwung River (see Table 1). These sampling efforts were coordinated with the DKI Jakarta Province’s Environmental Agency. The selected locations were strategically situated within the Ciliwung River watershed, specifically in the Ciliwung

Hulu-Manggarai subnetwork. Sample collection sites included the bridge on Kebahagiaan Street in Depok; bridges in Jagakarsa and Balekambang areas; the confluence of two river branches in Kalibata; a bridge on Jalan Melayu Besar 2; and a bridge on Jalan Slamet Riyadi in Jakarta (see Figure 1).

Figure 1 Sampling Points for Water and Sediment in Ciliwung River

Table 1 Coordinates of Water and Sediment Sampling Points of Ciliwung River

| Point | Site | Latitude | Longitude |
|---|---|---|---|
| 1 | Jalan Kebahagian, Depok | 6° 20' 48.113" S | 106° 50' 17.761" E |
| 2 | Jagakarsa | 6° 18' 53.960" S | 106° 51'3.956" E |
| 3 | Balekembang | 6° 17' 33.500" S | 106° 51' 12.600" E |
| 4 | Jalan Raya Kalibata | 6° 15' 46.26" S | 106° 51' 34.73" E |
| 5 | Jembatan Kalibata | 6° 15' 29.434" S | 106° 51' 37.645" E |
| 6 | Jalan Melayu Besar 2 | 6° 13' 41.329" S | 106° 51' 52.636" E |
| 7 | Jalan Slamet Riyadi | 6° 12' 45.554" S | 106° 51'27.868" E |

The sampling process took place over two days, specifically on the 9th and 10th of March 2023, during both morning and afternoon sessions, where the rainfall data at various points along the Ciliwung River were monitored. The meteorological records revealed an average rainfall of 9.79 mm per day for the 2-day window preceding and encompassing the sample collection days, spanning from the 7th to the 10th of March 2023. The wet weather sampling was compared with a previous study that collected samples during dry weather conditions on November 14th and

November 15th, 2022. During these dates, the average rainfall was recorded at 4.49 mm/day, representing low rainfall conditions.

The primary objective of this study is to conduct a comparative analysis of microplastic abundance under distinct weather conditions by comparing the microplastic quantities in this study with a previous study by (Mahendra, 2023). In our current study, we focused on wet weather conditions, represented by the sampling period of March 9th and 10th, 2023. In contrast, the examination of dry weather conditions occurred on the 14th and 15th of November 2022. During the latter sampling period, the average rainfall data for the upstream and main river body between November 12th and November 15th, 2022, recorded at 4.49 mm per day, falls under the category of low rainfall.

## 2.3. Design Wave Sample Collection and Testing Method

### 2.3.1. Water Sample

Water samples were collected by SNI 6989.57:2008, which details the method for surface water sample collection using grab sampling. The equipment utilized included sample collection tools, field parameter measurement instruments, filtering apparatus, and containers for sample storage. A representative water sample of 10 liters was concentrated into a 200 ml aliquot to identify microplastic characteristics and materials. This sample was then transferred to a 100 ml bottle container fitted with a plankton net of 300 µm pore size.

The testing of water samples adhered to the National Oceanic and Atmospheric Administration (NOAA) method, with specific modifications for our study. Microplastic extraction involved the addition of 10 ml of a 10% NaCl solution to 10 mililiters (ml) of the sample, facilitating the separation of microplastics based on density. This mixture was stirred using a magnetic stirrer at 75°C for 30 minutes. A 30% hydrogen peroxide solution was added to remove organic materials and isolate microplastics. The mixture was stirred and heated at 50 rpm and 75°C for 10 minutes. Centrifugation at 5 rpm for 10 minutes followed, and the sample was subsequently filtered through Whatman filter paper with a 1 µm pore size using a vacuum pump. The filtered sample was then examined under a microscope for microplastic analysis.

### 2.3.2. Sediment Sample

Sediment samples were obtained using an Ekman grab sampler, effectively scooping up soft or muddy substrates from the waterbed. The required sample size for microplastic observation was 400 ml. The procedure for sediment sample testing was based on methodologies outlined in prior research (Ding et al., 2019). Samples were dried in an oven at 75°C for 24 hours to eliminate moisture. Microplastic extraction then employed a 100 ml solution of 36% NaCl, with the mixture heated and stirred at 100 rpm and 65°C for 24 hours. The mixture was allowed to settle, separating the supernatant containing extracted microplastics. Removal of organic content from the sediment was achieved using a 30% H2O2 solution, knowns as Peroxide Oxidation process (WPO), with 20 ml of this solution heated and stirred at the same conditions for 24 hours. The processed sample was filtered using filter paper and examined under a microscope for microplastics.

## 2.4. Data Analysis Method

### 2.4.1. Microplastic Abundance Calculation

The abundance of microplastics is quantified using the formula from NOAA. This calculation considers the number of particles recorded, the volume of water filtered for the water sample, and the amount of sediment used.

Microplastic abundance in water:

$$C = \frac{n}{V} \tag{1}$$

Microplastic abundance in sediment:

$$C = \frac{n}{m} \tag{2}$$

where $C$ is particle concentration (particle/liter), $n$ is the number of particles, $V$ is filtered water volume (L), and $m$ is dry sediment weight (100 grams). Significance testing is conducted to determine whether the correlation coefficient is statistically significant (Nurjanah, 2018). Significance testing can be carried out using a paired t-test. The paired t-test examines hypotheses for non-independent (paired) data. The research object undergoes two treatments, specifically differentiating rainfall-related weather conditions.

2.4.2. Correlation Test

This study tests the significance of microplastic abundance data under high and low rainfall conditions in the Ciliwung River. Significance testing is conducted to determine whether the correlation coefficient is statistically significant (Nurjanah, 2018). Significance testing can be carried out using a paired t-test. The paired t-test examines hypotheses for non-independent (paired) data. The research object undergoes two treatments, specifically differentiating rainfall-related weather conditions. The process of this test includes:

1) Determining the hypothesis of the test:

$$H_0 = \mu_1 - \mu_1 = 0 \tag{3}$$

$$H_1 = \mu_1 - \mu_1 \neq 0 \tag{4}$$

2) The significance level (α) is then determined, representing the probability of rejecting $H_0$ when it is true.
3) The degrees of freedom ($df$):

$$df = n - 1 \tag{5}$$

4) Mean of the difference between data 1 and data 2:

$$\bar{d} = \frac{\sum(d_1 - d_2)}{n} \tag{6}$$

5) The standard deviation of the difference in measurement between data 1 and data 2:

$$SD = \sqrt{\frac{1}{n-1}} \sum_{i=1}^{n}(y_1 - \bar{d})^2 \tag{7}$$

6) The $t_{value}$:

$$t_{value} = \frac{\frac{d}{SD}}{\sqrt{n}} \tag{8}$$

7) Determining the $t_{table}$ value based on the probability distribution table of $t_{values}$ With the given degree of freedom.
8) Comparing the calculated $t_{values}$ with the $t_{table}$ Value to conclude according to the following criteria:

$$\text{If } -t_{table} < t_{values} < t_{table}, \text{ then } H_0 \text{ is accepted}$$

$$\text{If } t_{values} < -t_{tabele} \text{ or } t_{values} > t_{table}, \text{ then } H_0 \text{ is rejected, and } H_1 \text{ is accepted}$$

where $H_0$ is the data which is not significantly different, $H_1$ is the data that is significantly different, $\mu$ is the mean of the data group, $n$ is the number of the data in the data group, $d$ is the value of the data group, $\bar{d}$ is the mean of the difference between data 1 and data 2, $y$ is the value of the difference between data 1 and data 2, and $SD$ is the standard deviation.

## 3. RESULTS AND DISCUSSION

### 3.1. Data Analysis Method

Microplastic abundance in the Ciliwung River was determined by examining filter papers under a microscope supplemented by a digital camera for precision in counting and recording (see Table 2).

Table 2. Microplastic Abundance Data in Water under Low and High Rainfall

| Point | Time of Collection | Microplastic Abundance (Particle/Liter) | |
|---|---|---|---|
| | | Low Rainfall | High Rainfall |
| 1 | Morning | 458 | 1444 |
| | Afternoon | 320 | 1430 |
| 2 | Morning | 491 | 968 |
| | Afternoon | 539 | 924 |
| 3 | Morning | 625 | 1378 |
| | Afternoon | 666 | 1056 |
| 4 | Morning | 546 | 930 |
| | Afternoon | 496 | 1106 |
| 5 | Morning | 741 | 1284 |
| | Afternoon | 567 | 890 |
| 6 | Morning | 639 | 816 |
| | Afternoon | 657 | 1058 |
| 7 | Morning | 429 | 1202 |
| | Afternoon | 729 | 1068 |

A correlation test was conducted to understand the impact of weather conditions on microplastic abundance. This analysis compared data collected in November 2022 (representing low rainfall) and March 2023 (representing high rainfall). Boxplot graphs were utilized to visualize the microplastic abundance data. These graphs effectively illustrate the distribution characteristics of the data under different weather conditions, including the maximum and minimum values, averages, and quartiles. The boxplot is instrumental in evaluating the variation and spread of microplastic abundance between the two datasets, providing insights into the influence of rainfall on microplastic concentrations in the Ciliwung River.

### 3.1.1. Microplastic Abundance in Water

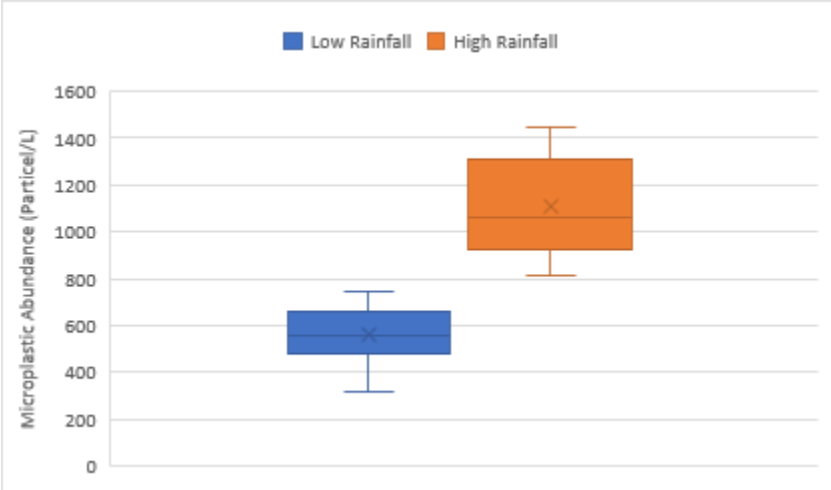


Figure 2 Boxplot Diagram of Microplastic Abundance Data in Water under Low and High Rainfall

Analysis of the boxplot diagram for microplastic abundance in water under low and high rainfall conditions reveals significant differences in data distribution (see Figure 2). The boxplot indicates that the range of microplastic particles in water during low rainfall is more compact, varying between 320 and 741 particles/liter. Conversely, the spread during high rainfall is broader, ranging from 816 to 1,444 particles/ liter. The horizontal lines at the extremities of the boxplot represent the maximum and minimum values.

The boxplot's interquartile range (IQR), representing 50% of the data, and the median values within the boxes suggest considerable differences between the two rainfall conditions. Specifically, the median microplastic abundance for low rainfall is 556 particles/ liter, with an average of 564 particles/liter. This proximity of the average to the median suggests a representative dataset. For high rainfall, the median abundance is 1,063 particles/ liter. The elongated box and whiskers for the high rainfall dataset indicate a more varied data distribution. Factors such as human activities and road runoff, which transport microplastics from tire abrasion into water bodies, could contribute to the observed variation (Kole et al., 2017).

Table 3 T-Test Results of Microplastic Abundance in Water

| Parameter | Low Rainfall | High Rainfall |
|---|---|---|
| Mean | 565 | 1.111 |
| Variance | 14.373,65 | 42.607,85 |
| Observation | 14 | 14 |
| Pearson Correlation | -0,31 | |
| Hypothesized mean difference | 0 | |
| $df$ | 13 | |
| $t_{value}$ | -7,59 | |
| $t_{table}$ | 2,16 | |

The t-test analysis reveals a calculated t-value of -7.59 and a t-table value of 2.16 (see Table 3). The observed t-value of -7.59, being less than the negative of the t-table value (-2.16), leads to the rejection of the null hypothesis (H0) and acceptance of the alternative hypothesis (H1). This

result implies a significant difference in microplastic abundance between low and high rainfall conditions, indicating no direct correlation between the two.

While rainfall impacts river flow rate and current turbulence, which in turn can influence microplastic distribution, this study suggests that the quantity of microplastic abundance is not directly correlated with rainfall levels. Other factors, such as domestic activities and varying degrees of rainfall, may also play a role in this observed difference in microplastic abundance.

### 3.1.2. Microplastic Abundance in Sediment

Microplastic abundance in sediment samples was evaluated under varying rainfall conditions to determine the influence of environmental factors on microplastic distribution (see Table 4).

Table 4 Microplastic Abundance Data in Sediment under Low and High Rainfall

| Point | Time of Collection | Microplastic Abundance (Particle/100 gram) | |
|---|---|---|---|
| | | Low Rainfall | High Rainfall |
| 1 | Morning | 912 | 1944 |
| | Afternoon | 656 | 2085 |
| 2 | Morning | 980 | 1338 |
| | Afternoon | 1019 | 1450 |
| 3 | Morning | 885 | 1453 |
| | Afternoon | 988 | 1568 |
| 4 | Morning | 1063 | 2037 |
| | Afternoon | 736 | 1787 |
| 5 | Morning | 849 | 1402 |
| | Afternoon | 730 | 1282 |
| 6 | Morning | 924 | 1352 |
| | Afternoon | 990 | 1495 |
| 7 | Morning | 828 | 1509 |
| | Afternoon | 878 | 1466 |

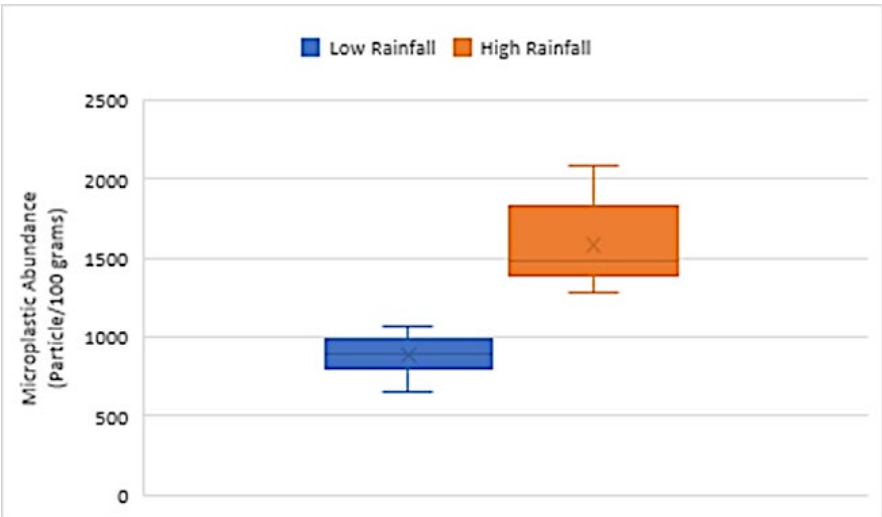


Figure 3 Boxplot Diagram of Microplastic Abundance Data in Sediment under Low and High Rainfall

Analysis of the boxplot diagram reveals a clear distinction between low and high rainfall conditions regarding microplastic abundance (see Figure 3). Under low rainfall, the abundance of microplastics in sediment ranges from 656 to 1,063 particles/100 grams. The distribution is

more condensed than high rainfall conditions, which show a wider range of microplastic abundance.

The average microplastic abundance for high rainfall is 1,583 particles/100 grams, indicating a substantial increase compared to low rainfall conditions. However, the distribution is not symmetrically centered around the median, suggesting that the mean may not fully represent the dataset. The median value under high rainfall is significantly higher at 1,480 particles/100 grams.

Table 5 T-Test Results of Microplastic Abundance in Sediment

| Parameter | Low Rainfall | High Rainfall |
|---|---|---|
| Mean | 888 | 1.583 |
| Observation | 14.280,4 | 71.425 |
| Pearson Correlation | 14 | 14 |
| Hypothesized Mean Difference | -0.14 | |
| $df$ | 0 | |
| $t_{values}$ | 13 | |
| $t_{table}$ | -8,46 | |

The t-test analysis indicates a t-value of -8.46, which, when compared to the t-table value, suggests a significant difference in microplastic abundance between the low and high rainfall conditions (see Table 5). This outcome aligns with studies indicating that rainfall can influence the distribution of microplastics in sediments, though other factors such as river flow dynamics, sedimentation processes, and human activities also play a crucial role (Barrows et al., 2018; Wei et al., 2022). In summary, while rainfall impacts the abundance of microplastics in river sediments, the correlation test results and the observed distribution patterns suggest that a combination of environmental and anthropogenic factors contribute to the variations in microplastic concentrations.

### 3.2 Microplastic Shapes in High and Low Rainfall Conditions

The shapes of microplastics are influenced by their sources, with fragments being the predominant form in high and low rainfall conditions. Fragments represent hardened and serrated plastic particles categorized as secondary microplastics, originating from durable polymer plastics like polypropylene, polyethylene, and polystyrene (Lassen et al., 2015). These fragments result from the breakdown of larger plastic items, often found within the Ciliwung River due to various types of waste along its course. Notably, a higher quantity of waste in the riverbed is associated with increased microplastic abundance, particularly in the form of fragments.

In water samples: During high rainfall, water samples exhibited a greater prevalence of fragment-shaped microplastics, as indicated by their higher abundance, than in low rainfall conditions. The quantification results revealed irregularly shaped fragments ranging from 788 to 1,402 particles per liter (particles/liter). Conversely, fragment-shaped microplastics ranged from 303 to 721 particles/liter under low rainfall conditions. Despite a significant difference in the quantity of fragments between the two conditions, the fragment shape remained dominant in both water and sediment samples.

In Sediment Samples: Sediment samples collected during high rainfall contained between 1,239 and 2,036 particles per 100 grams of dry sediment (particles/100 grams). In contrast, sediment samples obtained during low rainfall exhibited a narrower range, with fragment-shaped microplastics ranging from 622 to 1,058 particles/100 grams of dry sediment. The variation in

the number of fragment-shaped microplastics in sediment samples corresponds to the disparities in their abundance under different rainfall conditions.

Fragment-shaped microplastics' dominance in high and low rainfall conditions highlights their prevalence in the Ciliwung River. The presence of these fragments underscores the importance of addressing plastic waste management to reduce the potential sources of microplastic pollution in aquatic ecosystems. These findings contribute to our understanding of the impact of rainfall on microplastic shapes and their abundance in the river's environment.

### 3.3 Microplastic Color in High and Low Rainfall Conditions

Microplastics can be identified based on their color, which may originate from the plastic material and can be influenced by surrounding natural factors and climate conditions. Additionally, color changes or discoloration can occur due to exposure to UV radiation from sunlight, causing microplastics to appear bright or transparent. In high and low rainfall conditions, black emerges as the most dominant color in water and sediment samples.

The identification results indicate that black-colored fragment microplastics prevail in all samples, regardless of the prevailing weather conditions. The prevalence of black fragment microplastics suggests that most of these fragments originate from the fragmentation of black-colored plastics or are eroded from vehicle tires on roads, subsequently entering water bodies as runoff (Ziajahromi et al., 2020).

It is important to note that the color of microplastics can also be influenced by factors such as UV exposure from sunlight. This exposure can lead to color changes or discoloration, making microplastics appear brighter or even transparent. Understanding the impact of UV radiation on microplastic color is crucial for comprehending the dynamic nature of these particles in aquatic environments.

The dominance of black-colored microplastics, particularly fragments, in high and low rainfall conditions underscores their prevalence in the Ciliwung River. These findings shed light on the sources of these microplastics and their potential environmental impacts. Furthermore, the influence of UV exposure on microplastic color highlights the need for further research into the effects of environmental factors on microplastic characteristics.

## 4. CONCLUSION

Microplastic pollution in the Ciliwung River is a significant concern, with microplastics identified in water and sediment samples at all sampling points. The abundance of microplastics exhibits variations at each sampling point, primarily attributed to domestic activities and other contributing factors. In this study, we conducted a comparative analysis of microplastic abundance under different weather conditions, specifically high and low rainfall.

The results of the t-test indicate that there is no statistically significant relationship between rainfall and microplastic abundance in both the river's water and sediment. However, differences in average microplastic abundance in water and sediment can be influenced by other factors, including domestic activities, road runoff, and water flow dynamics.

Among the microplastic shapes identified, black-colored fragments are the most commonly found in water and sediment samples under high and low rainfall conditions. These black fragments likely originate from various sources, including the fragmentation of black-colored plastics and tire abrasion from road surfaces, which eventually enter water bodies through runoff.

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# A SPATIOTEMPORAL ANALYSIS OF ORGANIC POLLUTANTS CONTAMINATION IN CILIWUNG RIVER, INDONESIA

Mochamad Adhiraga Pratama[1*], Dorothy Marsha Constantine[1]

[1]Environmental Engineering, Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI, Depok 16420, Indonesia

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## ABSTRACT

Indonesia's DKI Jakarta province faces the ongoing issue of river pollution in the Ciliwung River, stemming from a variety of sources including domestic, commercial/industrial, and agricultural activities, exacerbated by the region's rapid population growth and associated shifts in land use patterns. Therefore, this study aims conduct a comprehensive spatiotemporal analysis of pollutant concentrations within the Ciliwung River and explore their correlation with land use changes to identify the predominant factors influencing river pollution. The investigation focuses on key organic pollutant parameters particularly focusing on Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), and Total Suspended Solids (TSS) and utilizes flow and water quality data sourced from Ciliwung-Cisadane River Basin Center. Spatially, the findings of this study indicate that there is an increasing concentration of organic pollutants from the river's upstream to downstream segments. Temporally, concentrations of organic pollutants, particularly BOD and COD, reached their peak in 2018 and subsequently exhibited a declining trend until 2020. The study also reveals a moderate to strong correlation between residential land use and increased pollution levels. These findings highlight the urgent need for integrated river basin management and policy implications to mitigate the environmental risks posed by escalating urbanization.

*Keywords*: Ciliwung organic pollutant; Spatial analysis; Temporal analysis

## 1. INTRODUCTION

The Ciliwung River, flowing through the heart of Jakarta, the Capital City of Indonesia, is a vital natural resource for the city, providing water for various needs such as drinking, industry, fishery, and agriculture (Hendrawan, 2007). Several reports highlighted that the river's water quality has deteriorated despite its critical role. A rising trend of water pollution in the Ciliwung River from upstream to downstream has been observed, with domestic activities identified as the dominant source of pollution due to high concentrations of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia, phosphate, detergent, and coliform bacteria (Ratnaningsih et al., 2019; Yudo, 2010).

Building upon previous studies, which have shown that factors like stream flow, soil moisture, antecedent streamflow, vegetation cover, and water temperature significantly affect the temporal water quality of rivers (Guo et al., 2018), this study aims to extend the analysis to more recent trends and deeper correlations.

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*Corresponding author's email: adhiragapratama@ui.ac.id
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Baba and Gunduz (2017) indicated that geogenic alteration zones and anthropogenic intervention influence the temporal variability of river water quality. The land use change in the watershed, closely associated with human activities, has led to significant changes in river water quality. It is supported by Pratama et al. (2020) that stated that significant correlations between land use and water quality in the Code River in Yogyakarta, Indonesia. Furthermore, hydrological processes affect the spatial distribution of organic pollutants in a river and cause a decline in quality at the river delta are also influenced by land use characteristics in a particular area.

In recent decades, the condition of the Ciliwung watershed in Jakarta has worsened due to uncontrolled land use changes, notably the increase in residential and built-up areas at the expense of agricultural land (Fachrul et al., 2007). The land use composition in the catchment area is strongly correlated with the amount of water runoff that flows into the water body (Qin et al., 2010), and changes in this composition, such as decreases in recharge areas and agricultural land, can greatly influence runoff and soil erosion (Dunjó et al., 2004).

Given its critical roles, it is essential to understand the spatial and temporal variability of the Ciliwung River's quality. While several studies have reported the water quality trend from upstream to downstream of the river, there remains a gap in the temporal analysis of river quality, particularly in recent years. Although Ratnaningsih et al. (2019) reported a low-significance trend of river quality through the 2011-2014 period, updating the analysis to recent years is important. Therefore, this study aims to analyze the spatiotemporal trend of the organic pollutant concentration in the Ciliwung River and its correlation with the trend of land use changes, focusing on the last five years (2016-2020). Water quality monitoring data from five stations provided by the Ciliwung–Cisadane River Basin Center (BBWS) were collected for this period. Land use changes through the same period were analyzed using geographic information system (GIS) tools, allowing for more accurate visualization and in-depth analysis of the impacts of these changes on water quality.

## 2. METHODS

### 2.1. Study Area

The Ciliwung River, which flows through several administrative areas, including Bogor Regency, Bogor City, Depok City, and Jakarta Province Capital City, displays diverse geographical characteristics. From its mountainous origins in Bogor to the low-lying plains in Jakarta, these varying landscapes significantly influence the river's water quality and flow patterns. According to DKI Jakarta Provincial Environmental Service, the river extends over a length of approximately 120 kilometers (km), encompassing a river basin area of 387 $km^2$.

The Ciliwung River passages through numerous villages, dense residential areas, and slum settlements. The level of sanitation in these areas directly impacts the river's health. As of 2021, data from the Central Statistics Agency revealed that in West Java and DKI Jakarta Province, the percentage of households with access to adequate sanitation facilities stood at 71.66% and 95.17%, respectively. Adequate sanitation is defined as having individual or communal defecation facilities, using a gooseneck toilet, and a final disposal site for feces in a septic tank, Wastewater Treatment Plant (WWTP), or in a hole in the ground for rural areas.

Apart from domestic activities, land-based activities such as agriculture play a significant role in the catchment area's environmental dynamics. Using fertilizers and pesticides in extensive agricultural lands along the Ciliwung River Basin can increase nutrient levels and pollutants in the river water. According to the 2015-2019 Agricultural Land Statistics Report, the total agricultural land in the Province of DKI Jakarta, Depok City, Bogor City, and Bogor Regency in 2019 amounted to 46,648 hectares, most of which falls within the Ciliwung River watershed.

## 2.2. Data Collection

2.2.1. River Water Quantity and Quality

In this study, river discharge and water quality data were compiled from the BBWS report for the 2016 – 2020 period. Five strategic monitoring points were selected to measure river discharge and water quality, namely: Katulampa (TP 1), Kampung Kelapa (TP 2), Panus Bridge Depok (TP 3), MT Haryono (TP 4), and Manggarai Gate (TP 5). These points were chosen as they represent the river's upstream, midstream, and downstream sections, providing a comprehensive overview of the water quality changes along the river's course, as shown in Figure 1.

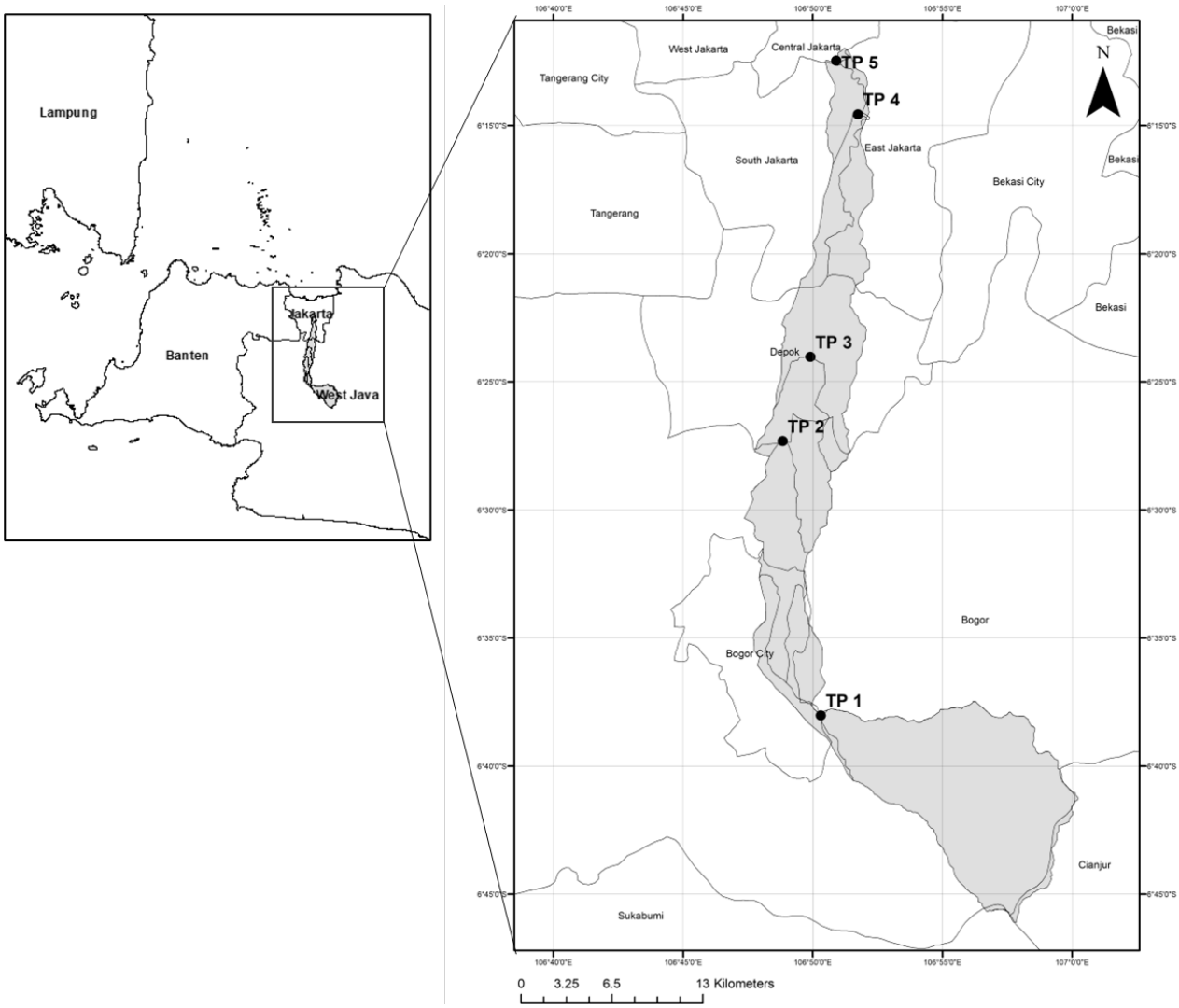



Figure 1 Study area and monitoring stations

The river discharge and water quality data were collected during the second semester (July – December) of each year from 2016 to 2020. Although the discharge measurement and water quality sampling were not conducted simultaneously each year, this methodology ensures consistency and accuracy in data collection. Four water quality parameters were analyzed to indicate the presence of organic pollutants, namely BOD, COD, DO, and TSS. The measurement methods for these parameters are detailed in Table 1.

Table 1 Water Quantity and Quality Parameter Measurement Method

| Parameter | Method | Code |
|---|---|---|
| Discharge | Current meter | SNI 8066 2015 |
| BOD | Five days incubation | SNI 6989.72:2009 |
| COD | Spectrophotometric | SNI 6989.02:2019 |
| DO | Potentiometric | SNI 06989.14-2004 |
| TSS | Gravimetric | SNI 6989.3:2019 |

2.2.2. Land Use

For land use data, this study utilized shapefile data resulting from land cover recalculations from digital data available at the Directorate of Forest Resources Inventory and Monitoring and the Directorate General of Forestry Planning and Environmental Management under the Indonesia's Ministry of Environment and Forestry. On a scale of 1:250,000 accuracy, the data is used to obtain the percentage of each land cover type from 2016 – 2020. This detailed and accurate data will be instrumental in correlating land use changes with water quality trends, providing insights into the impacts of human activities on the Ciliwung River.

### 2.3. Data Analysis

The data analysis in this study was conducted using IBM SPSS Statistics 26. Prior to the correlation analysis, the data underwent a comprehensive cleaning process that included removing incomplete entries, correcting measurement errors, and handling outliers, ensuring the integrity and reliability of the dataset.The selection of the trendline type was based on a thorough analysis of the data distribution, which involved visually examining the data and statistical methods to ensure that the chosen trendline accurately reflected the observed trends.

Correlation analysis was then carried out to examine the relationship between pollutant concentration values and land cover percentage. This was done using the Pearson Correlation Coefficient (r), which measures the strength and direction of the relationship between two variables, x and y, in the sample. The Pearson r value was calculated to determine the degree to which changes in land use correlate with changes in the concentration of pollutants in the river.

The results of the correlation analysis will be presented in tables and graphs for interpretation and of how land use influences the water quality of the Ciliwung River, providing insights into the dynamics between human activities and environmental impacts.

## 3. RESULTS AND DISCUSSION

### 3.1. Data Summary

Tables 2 and 3 provide a descriptive statistical summary of the water quality of the Ciliwung River from 2016 to 2020 at each monitoring station and for each year of the study. These tables highlight critical areas with BOD concentrations exceeding class II water quality standards 27 times, according to the Republic of Indonesia Government Regulation Number 22 of 2021 regarding Implementation of Environmental Protection and Management. COD, DO, and TSS concentrations exceeded the standards 13, 9, and 2 times. These summaries underscore areas and times where focused environmental management interventions are needed.

Table 2 Spatial Summary of Wtaer Quality of Ciliwung River in 2016 – 2020

| Parameter | | Concentration (mg/L) | | | | |
|---|---|---|---|---|---|---|
| | | TP 1 | TP 2 | TP 3 | TP 4 | TP 5 |
| BOD | Mean | 4.1 | 4.6 | 5.2 | 7.2 | 6.2 |
| | Median | 3.3 | 3.2 | 5.0 | 7.0 | 5.0 |
| | St. Dev | 1.7 | 2.3 | 2.4 | 0.4 | 3.1 |
| | n > QS | 3 | 3 | 4 | 5 | 4 |
| COD | Mean | 18.5 | 19.1 | 25.1 | 30.4 | 24.4 |
| | Median | 17.0 | 14.0 | 23.0 | 30.8 | 18.8 |
| | St. Dev | 6.7 | 10.6 | 5.9 | 3.4 | 11.7 |
| | n > QS | 1 | 1 | 2 | 4 | 2 |
| DO | Mean | 4.8 | 4.7 | 4.8 | 4.5 | 3.9 |
| | Median | 4.7 | 4.4 | 4.6 | 4.0 | 3.6 |
| | St. Dev | 1.3 | 1.9 | 1.3 | 1.8 | 1.7 |
| | n > QS | 1 | 1 | 1 | 2 | 3 |
| TSS | Mean | 18.2 | 14.8 | 16.8 | 22.0 | 31.8 |
| | Median | 14.0 | 14.0 | 15.0 | 18.0 | 20.0 |
| | St. Dev | 8.9 | 7.7 | 9.1 | 11.4 | 23.6 |
| | n > QS | 0 | 0 | 0 | 0 | 1 |

Spatially, TP4 exhibited the highest BOD and COD concentrations, whereas TP5 showed the most significant pollution in DO and TSS. TP1 appeared to be the least polluted, with the lowest BOD and COD concentrations and the highest DO levels. However, there were occasions (1-3 times) when water quality at this station exceeded quality standards. Temporally, 2018 emerged as the most polluted year, with average BOD, COD, and DO concentrations of 7.6 mg/L, 34.4 mg/L, and 3.8 mg/L, respectively (see Table 3). In contrast, the TSS concentration was lowest in 2018, suggesting a lower impact of rainfall on sediment transport.

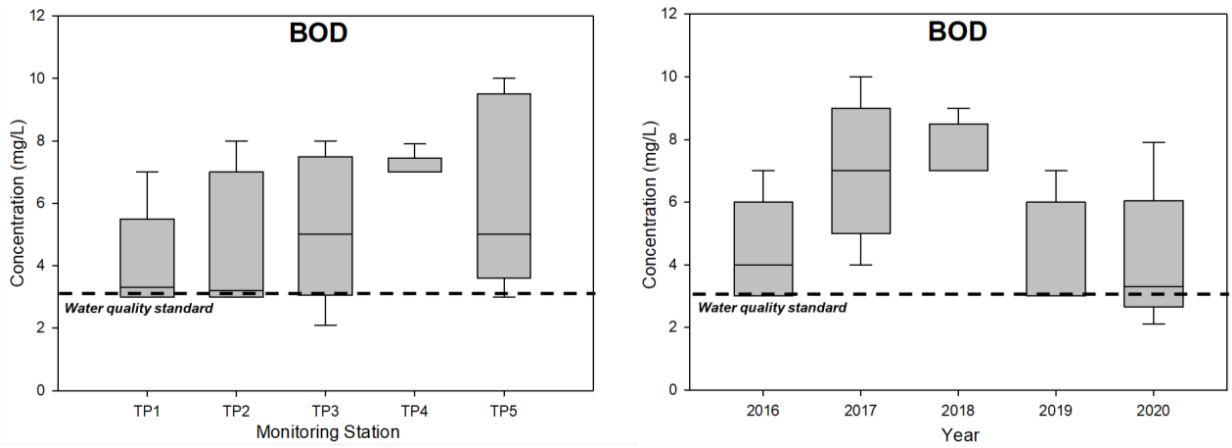
Table 3. Temporal Summary of Water Quality of Ciliwung River in TP1 – TP5

| Parameter | | Concentration (mg/L) | | | | |
|---|---|---|---|---|---|---|
| | | 2016 | 2017 | 2018 | 2019 | 2020 |
| BOD | Mean | 4.4 | 7 | 7.6 | 4.2 | 4.1 |
| | Median | 4 | 7 | 7 | 3 | 3.3 |
| | St. Dev | 1.7 | 2.2 | 0.9 | 1.8 | 2.3 |
| | n > QS | 3 | 5 | 5 | 2 | 4 |
| COD | Mean | 18.2 | 24.8 | 34.4 | 18.4 | 21.5 |
| | Median | 18 | 25 | 34 | 14 | 22.3 |
| | St. Dev | 8.4 | 6.5 | 4.5 | 7.8 | 6.4 |
| | n > QS | 1 | 2 | 5 | 1 | 1 |
| DO | Mean | 5.2 | 6.8 | 3.8 | 4.2 | 2.7 |
| | Median | 5 | 6.8 | 4 | 4.4 | 2.6 |
| | St. Dev | 0.9 | 0.3 | 0.4 | 0.6 | 0.6 |
| | n > QS | 0 | 0 | 1 | 2 | 5 |
| TSS | Mean | 17.2 | 30.8 | 14.6 | 17.2 | 23.8 |
| | Median | 13 | 17 | 15 | 12 | 26 |
| | St. Dev | 15.9 | 22.6 | 1.7 | 9.8 | 7.4 |
| | n > QS | 0 | 1 | 0 | 0 | 0 |

### 3.2. Biological Oxygen Demand (BOD)

Figure 2a displays boxplots of BOD concentrations at each monitoring station. The trend of increasing BOD concentrations from upstream to downstream is evident, with the median values indicating the lowest concentration in TP1 and TP2, at 3.3 mg/L and 3.2 mg/L, respectively. The highest median value was at TP4, at 7.0 mg/L. Dissolved oxygen levels can influence BOD concentrations, suggesting varying self-purification capacities along the river (Wahyuningsih et al., 2019).

This explains why there is a turbulent flow at TP5, with a high discharge exceeding 300 $m^3$/second, likely enhances the reaeration rate, as indicated by the lower BOD concentration compared to previous stations. The fluctuating BOD concentrations from upstream to downstream may reflect the river's self-purification capability, as long as there is sufficient dissolved oxygen (Moersidik & Widhiasari, 2015). Figure 2b shows the temporal trend of BOD concentrations, peaking in 2017 and 2018 reaching 7 mg/L, and then declining in subsequent years to 3 mg/L and 3.3 mg/L, in 2019 and 2020, respectively. The overall increase in BOD concentrations from 2016 to 2020 was 11%, highlighting the need for a closer examination of specific changes or events during these years that may have impacted water quality.

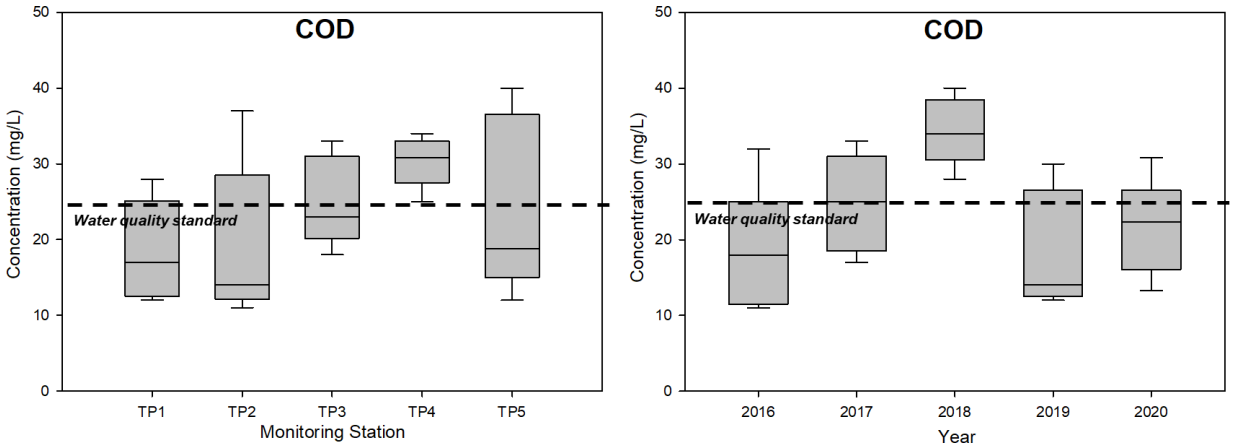



(a) (b)

Figure 2 Boxplots of BOD concentrations by monitoring stations (a) and by year (b)

### 3.3. Chemical Oxygen Demand (COD)

COD concentrations at each monitoring station are illustrated in Figure 3a through boxplots. The median COD concentration was lowest at TP2 (14 mg/L), indicating relatively better water quality at this upstream location. In contrast, the highest median value of 30.8 mg/L was recorded at TP4, suggesting significant organic pollution in this part of the river. Figure 3b, showing COD concentrations for each monitoring year, reveals a peak in pollution levels during 2017 and 2018, with concentrations reaching up to 34 mg/L. A subsequent decrease in 2019 and 2020 to 14 mg/L and 22.3 mg/L, respectively, was noted. Overall, there has been an 18% increase in COD concentration over the study period, indicating a rising trend in organic pollutant load each year.




(a) (b)

Figure 3 Boxplots of COD concentrations by monitoring stations (a) and by year (b)

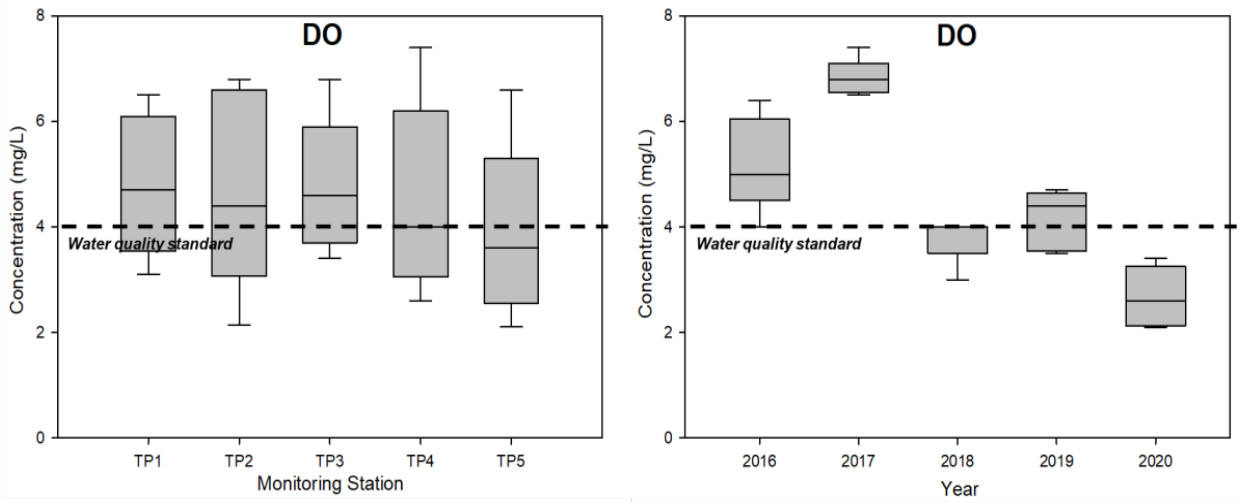
High COD levels in river water indicate a substantial amount of organic pollutants, encompassing both biodegradable and non-biodegradable substances (Islam et al., 2019). This study reveals a heavier pollution load in the downstream segment of the Ciliwung River, particularly in the DKI Jakarta area, compared to the upstream segments. This suggests that urbanization and industrial activities in these regions significantly contribute to the deterioration of water quality. COD, along with BOD, is a critical parameter for assessing wastewater characteristics. The decline in water quality in the Ciliwung River is not only a result of domestic waste but also due to commercial and industrial activities. Industries in the catchment area, especially those without adequate wastewater treatment facilities, contribute to the pollution load. The Ciliwung River, functioning as an open ecosystem, receives various pollutants through water channels. Industrial effluents discharged into these channels, which do not meet environmental standards, exacerbate the decline in water quality (Hasibuan, 2019).

This trend highlights the urgent need for integrated wastewater management strategies, encompassing domestic and industrial sources, to mitigate the impact on the river's ecosystem. Strengthening regulations and monitoring systems for industrial discharges, alongside promoting effective wastewater treatment solutions, will be crucial in improving the overall health of the Ciliwung River.

### 3.4. Dissolved Oxygen (DO)

The boxplots detailing DO concentration values across both monitoring stations and years was presented in Figures 4a and 4b. These plots reveal a discernible trend of decreasing DO concentration as we move downstream. Examining the median values, TP5 exhibits the lowest DO concentration at 3.6 mg/L, while the highest median value is observed at TP1 at 4.7 mg/L. Notably, the boxplots depict variations in DO concentration in the upstream river, with compliance with class II water quality standards as stipulated by the Government Regulation Number 22 of 2021. However, it's important to highlight that certain DO concentration data points at TP4 and TP5 exceed these standards. Additionally, the boxplots underscore that the most significant variation in DO concentration occurred in 2017, peaking at 6.8 mg/L, while the lowest median DO concentration value was recorded in 2020 at 2.6 mg/L. The fluctuations in both DO and BOD concentrations imply that the river's self-purification capacity varies at each monitoring point and in each year, a phenomenon likely influenced by hydrodynamic conditions. The process of gas transfer from air to water bodies, known as river hydraulic factors,

significantly affects the reaeration process. Overall, the trend in DO concentration reveals a decrease of -9%, indicating a decline in the water quality of the Ciliwung River over the study period.




(a) (b)

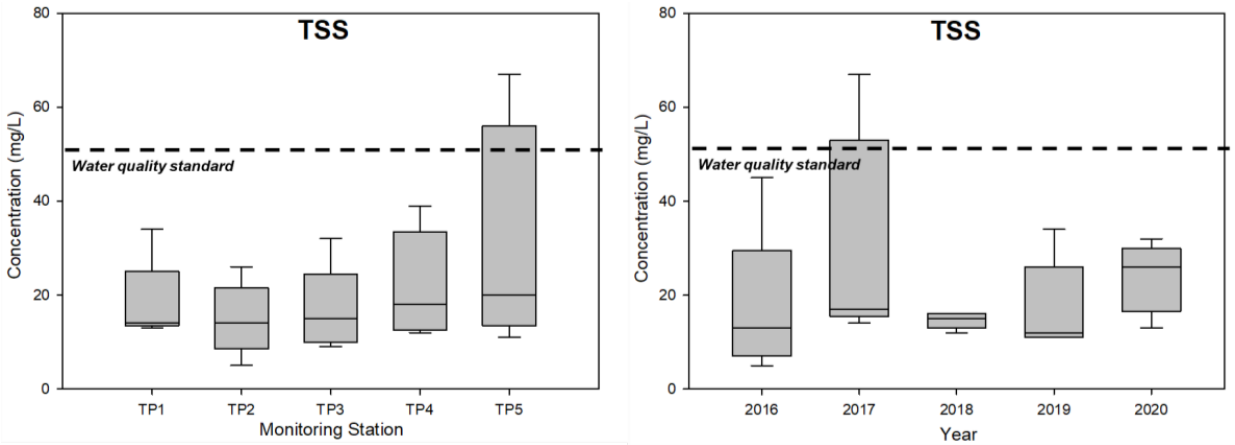
Figure 4 Boxplots of DO concentrations by monitoring stations (a) and by year (b)

DO is a crucial parameter for assessing water quality and ecosystem health. Insufficient oxygen levels can harm aquatic life, often resulting in fatalities not directly from pollutant toxicity but due to oxygen depletion caused by the biodegradation process of pollutants (Manahan, 2000). This trend suggests that the downstream segments of the Ciliwung River are increasingly unsuitable for sustaining freshwater ecosystems. High levels of BOD, indicative of organic waste, further exacerbate DO depletion in these water bodies (Penn et al., 2009).

The relatively better DO concentration in the river's upstream segments can be attributed to a lower deoxygenation rate than the reaeration rate. This balance is crucial for maintaining water quality, where a high deoxygenation rate is typically driven by the concentration of organic pollutants and their decomposition rate. Conversely, the reaeration rate, indicating the speed at which oxygen diffuses into the water, is essential for replenishing oxygen levels. A study on the Bedadung River in Jember Regency corroborates these findings, showing lower deoxygenation rates in rural areas compared to urban settings (Wahyuningsih et al., 2019). These findings underscore the critical need for effective management strategies to mitigate pollution sources, particularly in urban areas, to preserve the ecological integrity of the Ciliwung River.

### 3.5. Total Suspended Solids (TSS)

Figure 5a presents boxplots of TSS concentrations at each monitoring station along the Ciliwung River. These plots reveal an increasing trend in TSS concentration from upstream to downstream, with the lowest median concentrations observed at TP1 and TP2 (14 mg/L) and the highest at TP5 (20 mg/L). Despite this increase, all stations have TSS levels within class II water quality standards per the Government Regulation Number 22 of 2021, indicating a relatively stable water quality in suspended solids. The temporal analysis of TSS concentrations, illustrated in Figure 5b, shows the highest variation in 2020, reaching a median of 26 mg/L and the lowest in 2016 at 13 mg/L. Overall, there has been a 45% increase in TSS concentration over the study period, signifying a growing load of suspended solids entering the river each year.




(a) (b)

Figure 5 Boxplots of TSS concentrations by monitoring stations (a) and by year (b)

This rising trend in TSS is corroborated by the record rainfall in Jakarta since early 2020, as reported by the Meteorology, Climatology, and Geophysics Agency of Indonesia (BMKG). The highest recorded rainfall reached 377 mm/day, aligning with the increased river discharge data from Ciliwung–Cisadane River Basin Center, where the discharge at TP7 peaked at 386 $m^3$/second. Such high rainfall events, especially in urban areas like Jakarta, often result in elevated river TSS levels due to enhanced soil erosion and runoff, as river conditions during heavy rains typically lead to cloudier water with higher sediment content (Nurjanah, 2018).

Managing the Manggarai Sluice Gate, including the Ciliwung Lama and West Flood Canal, is crucial in controlling water overflow and sediment transport during these high rainfall events (Sari, 2020). The increased TSS levels in 2020 can be attributed to these extreme weather conditions, highlighting the need for effective sediment and stormwater management strategies, particularly in light of increasing urbanization and climate change impacts.

### 3.6. Land Use Trend Analysis

The land use map of the Ciliwung watershed from 2016 to 2020 is depicted in Figure 6 that clearly shows that the further downstream one goes, particularly in the MT Haryono watershed and Manggarai Gate areas, the more dominant residential areas become. This trend aligns with the urbanization patterns that Lambin (2001) identified, where urban agglomeration and suburban settlements that need to be expanded led in significant landscape changes. However, city centers that are already densely populated only experience a change from residential to commercial areas (Sari & Dewanti, 2018). This study includes industrial and commercial areas in the residential land classification, reflecting a nuanced perspective on urban land use. Thus, in the downstream segment of the Ciliwung River, the percentage of residential land has only experienced a small or even constant increase.

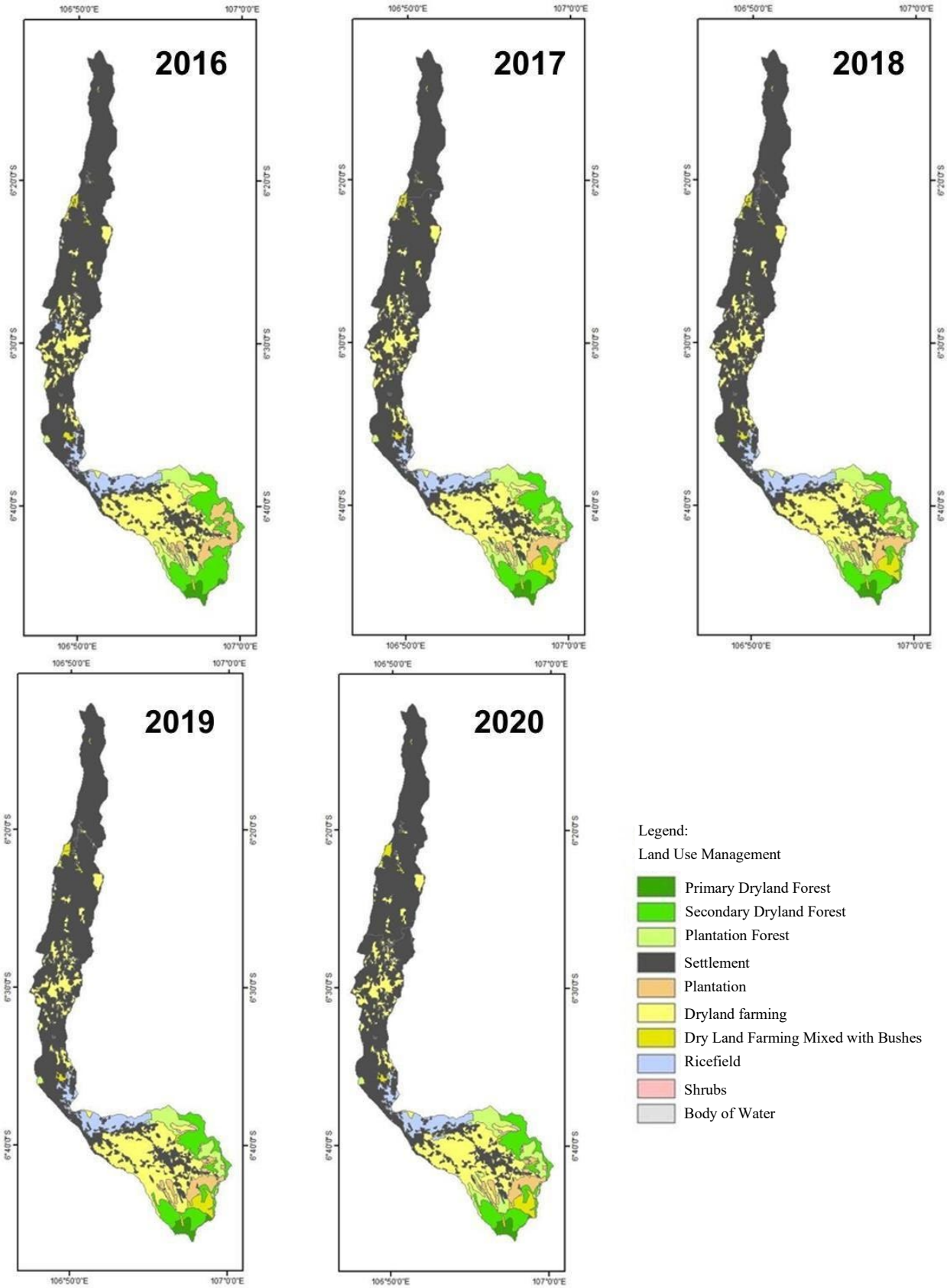



Figure 6 Land use change in the Ciliwung River watershed in 2016-2020

The percentage of residential land from 2016 to 2020 for each monitoring point river basin can be seen in Table 4. Residential areas in the Katulampa watershed only increased by 0.9% in 2017

and remained constant until 2020. The residential area in the Kampung Kelapa watershed increased by 2.8% in 2017, 0.2% in 2018, and 0.5% in 2019, and it remained constant until 2020. Residential land in the Panus Depok Bridge watershed increased by 2.5% in 2017 and remained constant until 2020. Residential land in the MT Haryono watershed increased by 0.1% from 2017 and remained constant until 2020, whereas residential land in the Manggarai Watershed did not increase from 2016 to 2020.

Table 4 Pearson Correlation Coefficient between Water Quality in each Monitoring Station versus Percentage of Residential Area in the Catchment Area of each Monitoring Station.

| Parameter | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|
| BOD | 0.664 | 0.861 | 0.466 | 0.405 | 0.364 |
| COD | 0.568 | 0.796 | 0.834 | 0.381 | 0.066 |
| DO | -0.555 | 0.516 | -0.447 | -0.728 | -0.482 |
| TSS | 0.377 | 0.649 | -0.422 | -0.891 | 0.676 |

Table 4 presents the Pearson Correlation Coefficients between water quality parameters at each monitoring station and the percentage of residential areas in their respective catchments. The findings reveal a moderate to strong correlation across all parameters, emphasizing the significant impact of residential land use on water quality. For example, BOD, commonly resulting from decomposable organic carbon from various sources including human activities, notably correlates with residential areas. This indicates the impact of domestic and commercial/industrial wastewater, which typically lacks proper treatment and directly contributes to river pollution (Penn et al., 2009; Putri, 2021). The strong positive correlation observed between residential areas and river COD concentrations (Suharyo, 2019) further underscores the need for comprehensive wastewater management.

The significance of the correlation between water quality in each monitoring station versus the percentage of residential area in the catchment area of each monitoring station may indicate the importance of a centralized wastewater treatment system. Although only around 4.83% – 28.34% of households do not have access to proper sanitation in Jakarta and West Java, only a few households have managed their greywater, as the common practice is direct discharge to drainage systems, which eventually ends up in water bodies. The current lack of proper sanitation in some areas of Jakarta and West Java, where direct discharge into water bodies is common, calls for urgent action.

Currently, the Ministry of Public Works and Housing, through the Directorate General of Human Settlements, in collaboration with the Japan International Cooperation Agency (JICA) assists the government of DKI Jakarta province to address the sanitation and wastewater issues by developing a Domestic Wastewater Treatment Plant system in key zones across Jakarta called the Jakarta Sewerage Development Project (JSDP). This project is a critical step towards mitigating river pollution and enhancing urban water quality.

In accordance with the 2012's master plan outlined in the Project for Capacity Development in the Wastewater Sector in DKI Jakarta, the strategic development of the wastewater sector in DKI Jakarta is organized into fifteen designated zones. Among these, Zone 1 and Zone 6, encompassing areas in Central Jakarta, West Jakarta, and North Jakarta, have been identified as the foremost priorities for development by the Ministry of Public Works and Housing. JSDP was planned to be built within DKI Jakarta's Zone 1. The estimated cost for this undertaking amounts to 185 billion Indonesian Rupiah (Kementerian PUPR, 2022). Commencing in 2023, the construction of Zone 1's wastewater treatment infrastructure is slated for completion in 2027.

## 4. CONCLUSION

This study conducted a comprehensive spatial and temporal analysis of organic pollutant concentrations in the Ciliwung River at five monitoring stations: Katulampa (TP1), Kampung Kelapa (TP2), Panus Bridge Depok (TP3), MT Haryono (TP4), and Manggarai Gate (TP5). Spatially, there is a discernible increase in the concentrations of BOD, COD, and TSS from upstream to downstream, with a range of 14-29%. Conversely, DO concentration exhibited a negative trend, decreasing by 9%. Temporally, the study period of 2016-2020 revealed a general decline in water quality. Specifically, an increasing trend in BOD, COD, and TSS concentrations was noted, ranging from 11-45%, while DO levels showed a decrease of 9%.

A key finding from the correlation analysis is the moderate to strong relationship between water quality at each monitoring station and the percentage of residential land in the corresponding catchment areas. This correlation underscores the significant impact of residential development and associated wastewater on river pollution. It highlights the urgent need to develop and implement centralized wastewater management infrastructure to address the increasing pollution load, particularly in urban areas.

The results of this study emphasize the critical role of integrated water resource management that considers land use changes and urbanization patterns. Effective wastewater treatment and management, especially in densely populated urban areas, are essential to mitigate the adverse effects on river ecosystems. The ongoing initiatives, such as the Jakarta Sewerage Development Project, are steps in the right direction and should be supported and expanded to improve water quality in the Ciliwung River and other similar urban river systems.

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# A STUDY ON THE PREFERRED TELEWORKING POLICY BY THE PRIVATE SECTOR AND ITS IMPLICATION TO THE DEMAND ON TRANSPORT INFRASTRUCTURE (CASE STUDY: GREATER JAKARTA AREA)

Alvinsyah[1*], Edy Hadian[2], Wahyu Aji Syahputra[1]

[1]Transport Research Group, Civil Engineering Department, Universitas Indonesia, Depok 16424
[2]Indonesian Urban Transport Research Institute, Depok 16416, Indonesia

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## ABSTRACT

This study examines the implementation of a teleworking policy with a work-from-home (WFH) scheme from a private company perspective and its implications on the Greater Jakarta's proposed urban rail network's carrying capacity. Using descriptive and inferential statistical analyses, a representative percentage of employees capable of working from home was determined. This figure, found to be sixty percent, was then employed in a macro transport model simulation to assess its impact on urban rail network demand. The results of the statistical analysis indicate that sixty percent of the company's workforce can still permitted to work remotely. The model simulation conducted indicates that with this the sixty percent reduction in working trips utilizing transit, the proposed urban rail network plan experiences insignificant alterations in the required carrying capacity. This finding highlights the resilience of the current urban rail network plans against substantial shifts in working patterns and provides insights for future urban transport planning in the context of evolving work modalities.

*Keywords*: Demand; Preference; Teleworking; Urban rail; Work from home

## 1. INTRODUCTION

Teleworking, a key Transportation Demand Management (TDM) strategy, has been effectively implemented for over forty years (Suzuki Goshima et al., 2023). Among various TDM policies, teleworking stands out for its lower user costs and rapid implementation time (Choo et al., 2005; Kim, 2017; Zhu & Mason, 2014). It substantially benefits employers and employees, including enhanced morale, increased productivity, and significant long-term cost savings for organizations (Bernardino, 2017). Studies have also noted that telecommuters often dedicate more time to work activities and demonstrate higher productivity than in traditional office settings (Grawitch & Barber, 2010; Kirk & Belovics, 2006).

Jakarta as a metropolitan city struggles with severe congestion challenges, as it was ranked 12th by Traffic Index in 2023 and 46th by TomTom (2022) in global congestion ratings. In light of this issue, TDM strategies, including teleworking, is crucial way to address it. Such strategies offer an alternative to conventional approaches focusing primarily on highway infrastructure expansion and traffic management schemes.

*Corresponding author's email: alvinsyah2004@gmail.com, Tel. +62-21-7270029, Fax. +62-21-7270028
DOI: 10.7454/jid.v6.i2.1120

The COVID-19 pandemic has significantly altered lifestyles and work habits globally, driving teleworking, particularly Work from Home (WFH) policy, to the forefront of operational adaptations by employers and employees. Despite initial mobility pattern shifts, returning to pre-pandemic norms is expected as pandemic-related restrictions ease (Eisenmann et al., 2021; Molloy et al., 2021; Nilles et al., 1976). However, the continuation of WFH post-pandemic has garnered interest in various European studies (Reiffer et al., 2023).

From a policy-making perspective, teleworking offers multifaceted advantages, particularly in addressing traffic congestion, energy savings, and air quality improvement. It mitigates public costs associated with productivity losses, travel delays, and congestion during peak commuting hours. Thus, policymakers view teleworking as an instrumental tool in urban transport management.

While initial teleworking research primarily focused on its potential to reduce travel and address mobility issues, contemporary studies have expanded to examine its impact on congestion, pollution, and overall mobility sustainability (Lier et al., 2014). Although much of the existing research focuses on telecommuters' behavior and related factors (Drucker & Khattak, 2000; Mokhtarian & Salomon, 1997; Singh et al., 2013), there is a noticeable gap in studies from employers' perspectives. Furthermore, research on teleworking's effect on transportation modes and network congestion is extensive (Choo et al., 2005; Helminen & Ristimäki, 2007; Lachapelle et al., 2017; Zhu & Mason, 2014), yet relatively few studies have investigated its implications on public transport demand in the aftermath of the pandemic (Tsavdari et al., 2022).

The enforced WFH policy during the pandemic has significantly impacted public transport by reducing overall commuting trips. On the supply side, social distancing measures have also affected the effective capacity of public transport vehicles, imposing additional costs on operators striving to maintain safe transport services. In many countries, since the total number of transport trips has decreased, the public transport market share has significantly declined (De Borger & Proost, 2022).

This study explores the potential post-pandemic implementation of teleworking policies and their impact on the demand of transport infrastructure plan. By integrating employer preferences on teleworking policy with the impact analysis of this policy to urban rail-based network plan carrying capacity demands, this research offers insights into the future of urban mobility in the context of evolving work patterns. Subsequent sections of this paper will cover the literature study, research methodology, employer-preferred teleworking scheme analysis, and its influence on Jakarta's urban rail network carrying capacity. The concluding section will summarize the findings of this research.

## 2. LITERATURE STUDY

### 2.1. Teleworking

Teleworking, introduced in the 1970s, refers to working remotely from an office headquarters location (HQ), often with flexible timing. In the USA, this practice is commonly known as telecommuting (Lin et al., 2006). Despite its four-decade history, teleworking lacks a universal definition, leading to ambiguity in its understanding and application (Suzuki Goshima et al., 2023). Over the years, the definition of teleworking has evolved alongside technological advancements. Initially, teleworking was described as using telecommunications technology from home or a nearby location during regular working hours as an alternative to commuting to a conventional workplace (Mokhtarian et al., 2004).

More recently, the Eurofound and the International Labor Office (2017) have broadened this definition to encompass work outside the employer's premises, facilitated by Information and

Communication Technologies (ICTs) such as computers, tablets, and cell phones. This modern interpretation of teleworking encompasses a variety of work arrangements that differ in duration, location, and frequency. Regarding duration, teleworking can be executed full-time, part-time, or intermittently as needed. The most common location for teleworking is the worker's home, although it can be practiced from various other locations.

Teleworking significantly influences the demand for passenger transport, particularly commuting. It impacts the volume of commuting trips and their average distances, especially when teleworking occurs from locations other than the worker's home. This shift in work dynamics, driven by technological advancements and changing organizational cultures, presents new challenges and opportunities for urban planning and transport management.

## 2.2. Admiralty Method

The macro (4-step) transportation model, pivotal for this study on the Greater Jakarta Area, incorporates four integral components: a Trip Generation model, a Trip Distribution model, a Mode Split model, and a Trip Assignment model. The fundamental concepts of this 4-step modeling approach are extensively documented in transportation planning literature, such as Ortuzar & Willumsen (2011) and Papacostas & Prevendeuros (2001). The choice of this model for the Greater Jakarta Area was driven by the availability and comprehensiveness of its origin-destination (O-D) database, as well as the four models mentioned above. This model, initially developed from various previous studies (Alvinsyah & Hadian, 2018), has undergone numerous updates, calibrations, and validations over time (Hadian & Alvinsyah, 2017; JakPro, 2019; Yooshin, 2022). The structure of the Admiralty model is discussed below.

### 2.2.1. Zoning System

The zoning system adopted for this study is based on the smallest administrative boundaries of *kelurahan* and *kecamatan*, with the Jakarta area further defined based on the block plan in each *kelurahan* as delineated in the Jakarta's Detail Land Us Plan. The model covers 1,443 zones, with 1,250 within DKI Jakarta province.

### 2.2.2. Transport Network Model

The transport network model utilizes highway network data, including geometric data, links, and node capacity, as well as public transport data that include the number of lines, line capacity, headway, and mode type. The Greater Jakarta (*Jabodetabek*) transportation network model comprises both road and public transport networks. Detailed illustrations and descriptions of these network models are available in JakPro (2019).

### 2.2.3. Trip Generation Model

The trip generation model, adopted from previous studies and utilizing the trip rate approach from the Japan International Cooperation Agency (JICA) study (2014), correlates socio-economic conditions, land use, and vehicular flow in and out of each zone. The model is a function of population parameters and Gross Regional Domestic Product (GRDP), as demonstrated in Alvinsyah & Hadian (2018) and Hadian & Alvinsyah (2017).

### 2.2.4. Trip Distribution Model

The O-D matrices, categorized by mode, purpose, and income level, are derived from primary survey results in previous studies (Alvinsyah & Hadian, 2018; Hadian & Alvinsyah, 2017). The Furness or double-constrained method estimates trip patterns, with matrices prepared for the target year based on socio-economic indicators and population data (Ortuzar & Willumsen, 2011).

2.2.5. Transit Assignment Model

In contrast to the allocation of private car assignments, transit assignment model comprises a multitude of components, including connections and segments that connect stations or stops. The ability of individual units and their corresponding frequencies are intrinsically tied to the notion of link capacity within this framework. The transit assignment computation of travel time encompasses various components, such as the duration of time spent in the vehicle, wait periods at stops, and access and egress times.

Additionally, the fare variable is a crucial component of this computation. In contrast to private car networks that establish monetary costs in relation to fuel consumption, travel distance, or time, the public assignment model places significant importance on the monetary cost, which is represented by the fare applied to each line service, within the larger context of generalized costs. The applied transit tariffs, which are expressed in units of 'time', come together with the total travel time to form the all-encompassing notion of "generalized costs." Further elucidation on the notion of "generalized cost" can be obtained through an examination of previous investigations conducted by Hadian & Alvinsyah (2017) and Alvinsyah & Hadian (2018).

EMME software is utilized to facilitate the assignment process, with the transit assignment mechanism detailed in Alvinsyah & Hadian (2018) and the mathematical formulation explained in Spiess and Florian (1989).

## 3. METHODS

### 3.1. Analysis of the Preferred Teleworking Scheme

Building on the worker-centric focus of previous teleworking studies, as discussed in the Introduction section, this research aims to analyze teleworking schemes from companies' perspective. Understanding the company's stance on teleworking is crucial, given that their acceptance significantly determines the feasibility of implementation. Previous research indicates a potential misalignment between worker preferences for teleworking and the preferences of their employers.

Given the lack of a standard definition of teleworking, for survey clarity, this study defines it as 'working from home'. This definition encompasses various teleworking arrangements without limiting them to specific locations, provided they maintain productivity. The methodology for analyzing employer preferences for teleworking schemes is divided into four main steps:

a) Step 1

The first step is to design a questionnaire adopting a preference survey approach (Ortuzar & Willumsen, 2011). The questionnaire consists of two sections: the company data and the preferences for the teleworking schemes offered. Information on the company, among other things, is the type or category of its business, the number of workers, and the work method after the pandemic (e.g., WFO, hybrid, or WFH). Meanwhile, preferences for teleworking schemes consist of two parts: the hypothetical conditions and the choice of the offered schemes. The hypothetical condition is required for respondents to select the teleworking schemes with the following details:

- Based on transportation conditions during the pandemic, the government plans to implement the same policy (e.g., teleworking/WFH) to reduce congestion and air pollution levels.
- The teleworking scheme consists of several options for reducing the number of employees working in offices. The company's decision on the option is considered not to harm the

company's business and refers to the WFH's experience during the pandemic in 2020.

- The questionnaire must be filled out by either the company owners, directors, or the officials whose positions have the authority to decide on work schemes for their employees.
- The choice of the offered teleworking scheme is the reduction percentage of workers per working day, namely 100%, 90%, 75%, 50%, 25%, 10% and 0%. Since this study adapts the concept of preference survey method, the magnitude of these percentages is determined arbitrarily and not based on any specific rule. This percentage value is to ease the respondent's understanding to decide their choice.

In parallel with the design process, prospective respondents of companies engaged in industry and services in Jakarta were listed through the IDN Financial websites.

b) Step 2

A pilot survey, both offline and online, was conducted among the listed companies, leading to questionnaire and method refinements. The primary survey followed, with a minimum sample size of 30 companies per category, to ensure feasibility for descriptive statistical analysis, considering the challenges in obtaining respondents.

c) Step 3

The survey data was processed to construct the distribution of the maximum teleworking scheme selected by respondents for each business category. A Shapiro-Wilk normality test determined the need for parametric or non-parametric inferential statistical tests. Comparative analysis, using the Mann-Whitney test, assessed differences across categories. If insignificant, data from different categories were combined for further analysis.

d) Step 4

After identifying a representative business category group, central values were calculated, with one value selected through a significance test to represent company teleworking scheme preferences. This selected value was a correction factor for trip generation in subsequent analyses.

### 3.2. Analysis of the Impact of the Teleworking Scheme on the Carrying Capacity of the Jakarta Rail Network Plan

The Jakarta Metropolitan Macro Transport Model is employed to assess the influence of the teleworking scheme on the Jakarta Rail Network Plan's demand. The model's modal split component is derived from mode share compositions in previous studies, such as abodetabek Urban Transportation Policy Integration Project Phase 1 (JUTPI-1) in 2012; Japan International Cooperation Agency-Creative Technology Solution (JICA-CTS) in 2016, and JUTPI Phase 2 in 2020. The analytical process is divided into four steps:

a) Building a basic scenario (without a teleworking scheme)

First, trip generation for each zone in Greater Jakarta is predicted using the base year model and annual trip growth rates (Yoshiin, 2022). The synthesized origin-destination (OD) matrix is then re-balanced using the double constraint method (Ortuzar & Willumsen, 2011). Concurrently, the Jakarta rail network plan scenario, based on the Jakarta Transportation Master Plan 2039 and adapted for 2030, is defined. Several planned rail corridors are integrated into the existing network (detailed in Appendix Table A-1). The planning year's OD matrix is divided into three mode-based matrices: cars, motorcycles, and transit, using previous studies' mode shares. The transit OD matrix is the basic scenario for transit assignment analysis.

b) Building scenarios with teleworking schemes

For scenarios incorporating teleworking, the proportion of work trips to total trips is first calculated, referencing prior studies (Hadian & Alvinsyah, 2017; Alvinsyah & Hadian, 2018). Then, the number of work trips in each destination zone is adjusted using the teleworking factor value determined from the preferred teleworking policy analysis. The correction for government institution employees uses the same teleworking factor due to the relative ease of implementing teleworking policies in the public sector compared to private companies. The model-based person trip matrix is re-balanced, reflecting the teleworking policy's impact, with the updated transit matrix forming the 'with teleworking scheme' scenario.

c) Model Simulation and Carrying Capacity Estimation

Transit assignment simulations for both the basic and teleworking scheme scenarios estimate the required carrying capacity for Jakarta's rail transport network. Operational characteristics of public transport (headway, mode capacity, average commercial speed), tariff structures, and amounts are based on assumptions from previous studies (Jakpro, 2019; Yooshin, 2022). These simulations provide estimates of potential demand for each rail corridor under both scenarios, determining the necessary capacity for each corridor in the network plan.

d) Comparison Analysis on Carrying Capacity

Differences in estimated demand between the two scenarios are analyzed to determine their impact on the planned rail infrastructure requirements.

Figure 1 outlines the research method framework adopted in this study, illustrating the sequential approach from scenario development to capacity analysis.

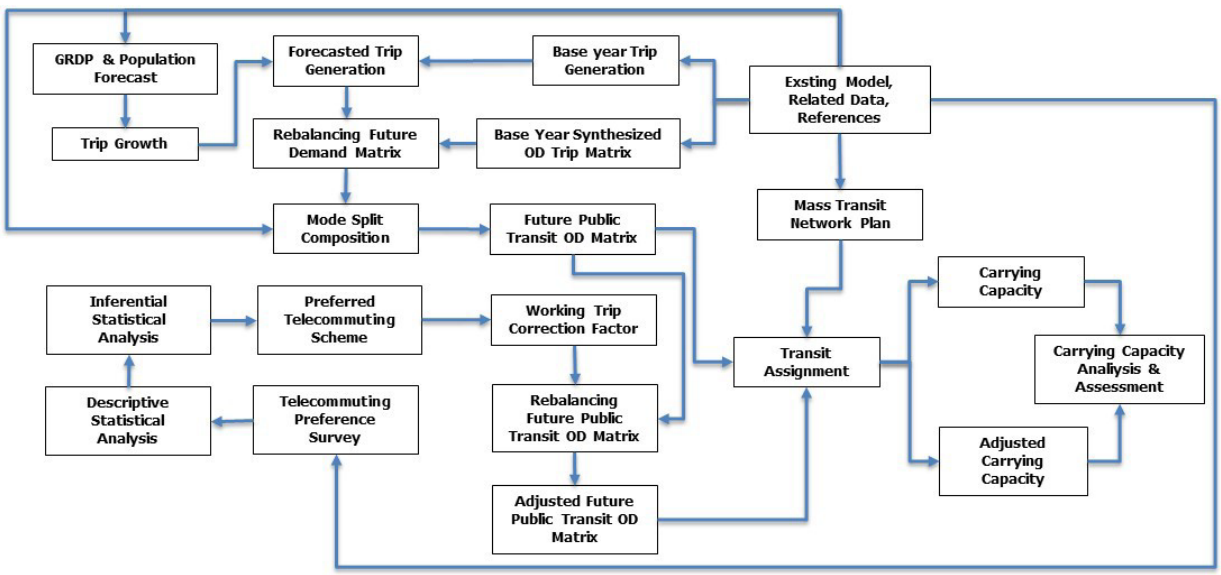


Figure 1 Research Method Framework

## 4. RESULTS AND DISCUSSION

The preference survey conducted for this study yielded 290 valid samples, comprising 173 from the services sector, 105 from the industry sector, and 12 from the agricultural sector. Due to the agricultural sector samples were less than 30, so they were excluded from further analysis. Of the

remaining sectors, only 94 service sector and 59 industrial sector samples—those implementing full-time office work—were considered for this study. The comparative analysis revealed that companies with a hybrid work scheme preferred WFH more than those predominantly working in the office. Furthermore, a sample adequacy test, comparing the maximum percentage of teleworking scheme choices from a minimum sample of 30 to larger multiples of 10, indicated no significant differences within each group, deeming the sample size sufficient for this study.

After the distribution of the service and industrial sector sample groups was attained, a comparative test was performed on the two distributions to obtain the value of the teleworking scheme that can represent the distribution of respondents' answers. However, before doing so, a distribution normality test was performed to determine the appropriate test instrument (e.g., parametric or non-parametric statistical test).

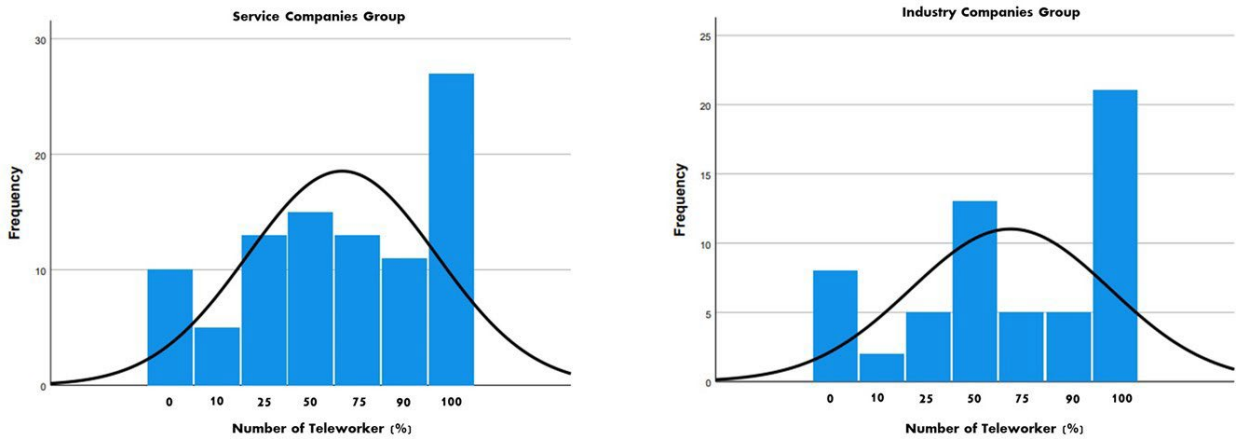


Figure 2 The Preferred Teleworking Scheme for Service and Industrial Companies

The normality test on the distributions of preferred teleworking schemes, as shown in Figure 2, exhibited a right-skewed distribution with a skew value greater than 2, as confirmed by mean values where the mode exceeded the median and the median exceeded the average (see Table 1).

Table 1 Preferred Teleworking Scheme

| MeanValue | Sectors | |
|---|---|---|
| | Industries | Services |
| Average | 61.60% | 63,05% |
| Median | 75.00% | 75.00% |
| Mode | 100.00% | 100.00% |

The Mann-Whitney test showed in Table 2 indicates that there is no significant difference between the two distributions, allowing their combination into one group for further analysis (see Figure 3).

Table 2 Homogeneity Test Result

| Test Method | Test Value |
|---|---|
| *Mann-Whitney U* | .000 |
| Asymp. Sig. (2-tailed) | .601 |

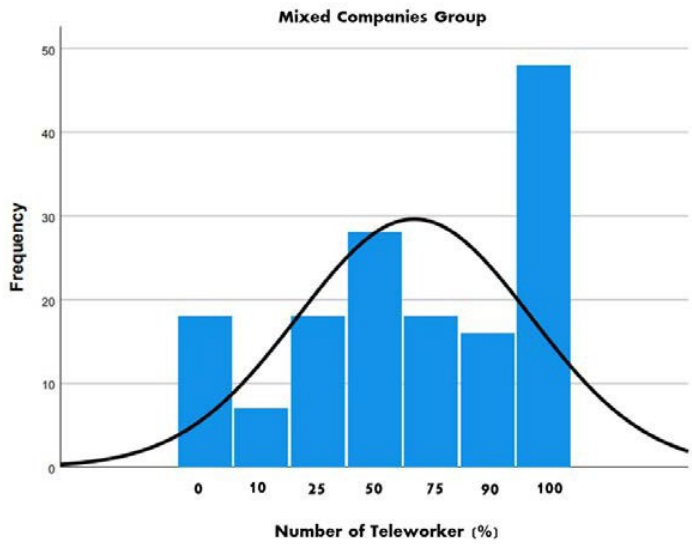


Figure 3 The combined preferred teleworking scheme

After calculating the mean, median, and mode values as has been summarized in Table 3, a Mann-Whitney significance test was performed. The average value (mean) emerged as the most significant, representing a 62.16% reduction in workforce numbers due to teleworking (see Table 4).

Table 3 Preferred Teleworking Scheme

| MeanValue | Worker Reduction (%) |
|---|---|
| Average | 62.16 |
| Median | 75.00 |
| Mode | 100.00 |

Table 4 Mann-Whitney Significance Test

| Mean | Asymp. Sig. (2 – tailed) |
|---|---|
| Average | .929 |
| Modus | .257 |
| Median | .926 |

Using the base year model and annual trip growth rates, the 2030 daily person trips in Greater Jakarta are estimated at approximately 73,387,283. The distribution of these trips by mode, with and without teleworking, is calculated and shown in Table 5.

Table 5 Total Estimated Trips in Jakarta in 2030 (Person-Trips/Day)

| Trip Mode | Without Teleworking Scheme | Mode Share |
|---|---|---|
| Car | 19,047,014 | 25.95% |
| Motorcycle | 44,377,831 | 60.47% |
| Transit | 9,962,437 | 13.58% |

Referring to Yooshiin (2022), the composition of work trips is 33.9% of the total trips in the Greater Jakarta Area. By implementing the teleworking policy where the number of teleworkers

is 62.16% of the working trip destined in Jakarta city, the composition of work trips is reduced to 20.05% as shown in Table 6.

Table 6 Corrected Total Working Trip in Jakarta (by Destination)

| Working Trip | Teleworking Correction Factor | Corrected Working Trip |
|---|---|---|
| 33.9% | 62.16% | 21.05% |

Furthermore, by carrying out the same correction process, the reduction of the working trips by cars, motorcycles and transit to the Jakarta area is shown in Table 7.

Table 7 Corrected Working Trip by Mode in Jakarta

| Mode | Person-Trips by Mode | Teleworking Composition |
|---|---|---|
| Car | 25.95% | 5.46% |
| Motorcycle | 60.47% | 12.73% |
| Transit | 13.58% | 2.86% |

Based on the percentage reduction in the number of working trips for car, motorcycles and transit as shown in Table 7, the estimated number of trips due to the implementation of the teleworking policy in the Greater Jakarta area in 2030 is shown in Table 8.

Table 8 Total Estimated Trips in Jakarta in 2030 (Person-Trips/Day)

| Trip Mode | Without Teleworking Scheme | Teleworking | With Teleworking Scheme |
|---|---|---|---|
| Car | 19,047,014 | 1,040,438 | 18,006,576 |
| Motorcycle | 44,377,831 | 5,648,825 | 38,729,006 |
| Transit | 9,962,437 | 284,785 | 9,677,652 |
| Total | 73,387,283 | 6,974,049 | 66,413,234 |

Referring to Table 7, the number of trips using transit destinated in the Jakarta Area due to the teleworking policy decreases by 2.86%. This reduction is not considered significant. On the other hand, the person trip reduction using motorcycles is relatively high at 12.73%. The analysis shows that the teleworking policy has a relatively small impact to the transit carrying capacity requirement. Furthermore, to obeserve whether the Jakarta planned urban rail infrastuctures need to be revised, a simulation with transit assignment is conducted to the teleworking scenario in Table 8. The results of the simulation are shown in Table 9.

Table 9 Total estimated maximum passenger flow in 2030 (Passenger/Peak-hour)

| Jakarta Rail Corridor | Without Teleworking Scheme | With Teleworking Scheme | Reduced Passenger Flow | Different (%) |
|---|---|---|---|---|
| Bogor Railway Line | 40,899 | 38,940 | 1,959 | 4.79 |
| Serpong Railway Line | 13,632 | 13,118 | 514 | 3.77 |
| Tangerang Railway Line | 13,779 | 13,298 | 481 | 3.49 |
| Bekasi Railway Line | 27,127 | 26,380 | 747 | 2.75 |
| LRT Gading - Manggarai | 1,417 | 1,389 | 28 | 1.98 |
| MRT East-West Line | 6,609 | 6,505 | 104 | 1.57 |
| LRT Pulo Gadung - Joglo Line | 5,855 | 5,739 | 116 | 1.98 |
| MRT Lebak Bulus – Kota Line | 5,287 | 5,248 | 39 | 0.74 |
| LRT Cibubur – Dukuh Atas Line | 6,759 | 6,503 | 256 | 3.79 |
| LRT Bekasi - Dukuh Atas Line | 7,329 | 7,280 | 49 | 0.67 |

The results of the transit assignment are consistent with the estimated trip due to the teleworking scheme shown in Table 8, where the reduction is relatively small. Since the peak hour demand is used for determining the carrying capacity, the operational design process, the proper type and technology of the mode, the values in Table 3.9 are in the peak hour. Referring to Table 9, the reduction rate of the potential demand is less than 5%, where the smallest reduction rate occurs on the Bekasi - Dukuh Atas LRT line and the largest on the Bogor - Jakarta Kota commuter line. Table 9 also shows that a relatively large reduction rate occurs on the "existing" commuter rail lines that carry commuting trips from buffer zones of Jakarta City. On the other hand, for the planned service lines soon, only the LRT Bekasi – Dukuh Atas line has a reduction rate equivalent to that of commuter rail lines. Based on the scenarios and assumptions defined in this study, the teleworking policy for workers working in Jakarta does not change the infrastructure needs as represented by the potential demand of the Jakarta rail transport network plan.

## 5. CONCLUSION

This study conducted a comprehensive analysis of teleworking schemes, focusing on reducing the workforce per day across various company types, and examined the impact of such schemes on the demand for transportation infrastructure. The preference survey revealed no significant difference in the choice of teleworking schemes among the participating companies. A detailed simulation of the Greater Jakarta transport model found that implementing a teleworking policy with a WFH scheme marginally affects the reduction of transit trips. Consequently, the projected need for rail-based mass transit network capacity remains largely unaltered.

However, the analysis highlighted that the teleworking policy notably influences the reduction of trips made by private vehicles, particularly among motorcycle users. This finding suggests that while the demand for public transit infrastructure may not significantly change, there is a pronounced shift in private vehicle usage patterns. Given this shift, there is a necessity for further studies to explore the implications of teleworking policies on highway usage and associated pollution levels.

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# THE PRESENCE OF MEMORY THROUGH MATERIALITY, SPATIAL CONFIGURATION, AND COLLECTIVE AS A SYSTEM FOR SUSTAINABLE HIGH-RISE RESIDENCE

Arnis Rochma Harani[1, *], Brigitta E. Mekarwangi[1], Muhamad I. Hasan[2]

[1]Department of Architecture, Faculty of Engineering, Diponegoro University
[2]Vocational College, Diponegoro University

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## ABSTRACT

This paper aims to explore the multifaceted elements involved in the design of residential buildings, encompassing both landed and high-rise structures, with a particular focus on memory. The ever-increasing urban population density has prompted a shift towards high-rise living, leading many individuals to transition from traditional landed homes. However, in urban environments where closely-knit communities have been the norm, high-rise living is often perceived as a potential obstacle to fostering social interactions akin to those experienced in landed residential areas. This challenge presents a compelling opportunity for designers to create vertical residential spaces that maintain the vibrant communal ambiance found in traditional neighborhoods. To address this challenge, the concept of interiority comes to the forefront, emphasizing the intricate interplay between individuals and their living environments. This paper adopts a design-based exploration methodology, drawing insights from various facets of interiority and integrating them into the design process. Through this exploration, the study underscores the pivotal role of memory in establishing a social ambiance during the transition from low-rise to high-rise living. The manifestation of memory is elucidated through three key dimensions: Spatial arrangements, cultural influences, and the thoughtful consideration of collective activities. These dimensions collectively form a comprehensive framework for developing high-rise residential structures that prioritize and enhance the social bonds among their residents.

*Keywords*: Memory; Strategy; Socio-spatial; Interiority

## 1. INTRODUCTION

In regions grappling with rapid population growth, the discourse often revolves around the scarcity of land for residential purposes. A potential solution to this challenge is transitioning from traditional land-based housing to high-rise buildings. Contemporary discussions on housing extend beyond its mere function as a dwelling place; they encompass its role as an economic entity (Betton, 2012; Harani et al., 2022; Marinic et al., 2021) and a workplace (Doling & Arundel, 2022; Werdiningsih et al., 2022) and even as a venue for entertainment (Werdiningsih et al., 2022). This multifaceted perspective underscores the adaptability of a well-designed living space to evolving circumstances (García de Paredes, 2022).

The transition from residing in landed properties to high-rise buildings (de Certeau et al., 1998) undeniably demands significant adjustment, particularly for individuals accustomed to confined living quarters and robust social connections. In the context of urban density, the topic of changing one's place of residence has also been a longstanding issue.

*Corresponding author's email: arnisrochmamaharani@lecturer.undip.ac.id
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Particularly, when currently there is a contemporary concept of a "garden city", a residential paradigm that considers the prac-tical aspects of habitation in the presence of industrialization (Howard, 2013).

Presently, densely populated urban areas face challenges, including the existence of densely populated urban "*kampungs*." In some regions, the solution has been to relocate these *kampungs* to high-rise buildings to optimize land utilization (Jantzen & Kaaris, 2007). Engaging the community in the development process of residential areas ensures that physical development is complemented by community growth (Andersen, 2007).

The significance of residential spaces is socially constructed and culturally rooted in the lives and surroundings of their inhabitants (Beer & Faulkner, 2011). Domesticity, in this context, extends beyond the physical confines of a dwelling to encompass the societal environment of its residents (Lawrence, 1981; Verschaffel, 2012). According to Lawrence (1981), social domesticity constitutes an integral aspect of a community's cultural milieu, daily life, and residential surroundings. de Certeau et al. (1984) argue that a neighborhood's cultural domesticity is shaped by the daily lives of its inhabitants, resulting in a distinct environmental atmosphere. While the contemporary discourse on housing underscores the importance of designing residential spaces that prioritize the well-being of their occupants, there has been limited exploration of the social significance of the built environment. The investigation into reconstructing a residential environment by integrating the old ambiance into a new dwelling offers a promising avenue for residential development in communities with strong social connections. Therefore, this study aims to explore into the myriad components that shape the presence of memory in residential buildings, particularly emphasizing the role of social engagement.

This study investigstes various facets of everyday life, particularly in landed houses characterized by robust social ties, to establish a foundation for designing high-rise buildings that preserve the traditional ambiance. Interiority, intricately linked with everyday practices and cultures (Atmodiwirjo & Yatmo, 2021), is inherent in habitation quality. Utilizing the concept of interiority as a lens allows us to comprehend better what it means to live in a society marked by high levels of social interaction. This study examines the socio-spatial aspects of everyday life in landed houses to inform the design of high-rise residential structures. The primary focus of this paper is on landed buildings as opposed to high-rise ones.

## 2. LITERATURE STUDY: THE CONCEPT OF HOME AND MEMORY

Memory is a cognitive process that involves the recollection of past experiences and can be reactivated when exposed to stimuli that recreate the original mental state. It is an integral part of daily life, involving repeated engagement with memories. De Certeau et al. (1998) exemplified memory by reconstructing childhood dialogues and cooking experiences with parents. Zumthor (2006) suggests that ambiance can trigger and activate recollections of events. This study explores how memory can be expressed, relocated, and reconstructed, particularly in residences with strong social interactions. It investigates how the interiority aspects of a lived environment impact memory retention.

On the other hand, the concept of home embodies a profound and emotional connection between individuals and their familiar surroundings (Ioannidou, 2021). It is deeply personal and intimately tied to its residents. Memories of home are shaped by inclinations, routines, and evolving needs that become intertwined with inhabitants over time. These memories are often recounted as personal narratives, rich with diverse experiences and constituent elements. Memories of one's place of origin are inherently linked to an individual and evoke associations with a lasting impact.

The global population surge has led to increased land requirements, prompting shifts in housing trends (Andersen, 2007). High-rise buildings are seen as a solution to address residential density issues, involving relocating city residents from densely populated areas to high-rise housing. This transition from landed housing to high-rises has introduced incompatibilities with traditional lifestyles, resulting in suboptimal structures. High-rise layouts often mimic low-rise houses, leading to increased complexity (Bruyns, 2018; Jantzen & Kaaris, 2007). Embedding a sense of geographical origin within residential structures is a pertinent consideration in contemporary housing discourse, especially in areas with low-income demographics (Beer & Faulkner, 2011). Incorporating memories of previous residences may help inhabitants adapt to unfamiliar surroundings.

Zouwer (2019) describes how immigrant parents transformed their residence's interior to recreate the familiarity of their hometown. Personal and domestic items played a crucial role in preserving memories. When viewed collectively, these items gain significance and offer diverse interpretations to a broader audience.

Salen (2016) discusses using photograms to translate interior spaces and stimulate a dialogue between imagination and memory regarding the representation and meaning of home. Photographic images can impact the recollection and evocation of the ambiance within participants' rooms. Memory is intertwined with an individual's spontaneous thoughts about their current situation perception, highlighting the connection between the physical body and its environment in forming memories (Sudarwanto et al., 2017). Examining how spatial settings evoke residential memories enriches our understanding of memory within architecture, particularly in housing design.

## 3. METHODS

The present study employs exploratory qualitative techniques (Creswell, 2009) to investigate high-rise buildings characterized by robust social ties, cultural significance, and everyday practices intricately linked to the physical environment. The primary objective of this research is to compile insights by exploring various dimensions of memory within the field of architecture, with a specific focus on space exploration and its interpretation (Wang & Groat, 2013). This study meticulously examines everyday practices by analyzing habits, lifestyles, and their closely associated components, particularly in the context of design.

Data collection for this study involved an extensive literature review utilizing various media sources, including online references and printed materials. The gathered data were categorized based on predefined criteria related to common experiences, design elements, and memory aspects, as Creswell (2009) outlined. The subsequent step involved subjecting these findings to exploratory analysis, incorporating design considerations. The ultimate goal is to generate design recommendations for high-rise residential structures considering daily life's and memory's intricacies.

## 4. RESULTS AND DISCUSSION

### 4.1. Memory Tracing through Occupancy Patterns

Inhabiting a physical environment involves the utilization of both physical and psychological faculties to establish a sense of spatial definition. The concept of space extends beyond the observable to encompass sensory experiences. Human response to a space or built environment is deeply intertwined with their inner character, fostering the emergence of intricate body-space relationships. These relationships significantly influence human behavior within a space,

ultimately shaping the overall atmosphere of the environment. Together, these aspects contribute to the experience of inhabiting and defining a space.

### 4.2. Reading References as a Basis for Understanding the Constituent Elements of Memory

To gain a comprehensive understanding of the components that contribute to the ambiance created by designers during the transition from landed to high-rise residential structures, it is crucial to deconstruct established precedents. In this phase, we draw upon the Sanjaynagar Slum Redevelopment Project as a precedent. This project, situated in Ahmednagar, Maharashtra, was executed by the Community Design Agency (CDA), a Mumbai-based social design and architecture studio, in collaboration with the Ahmednagar Municipal Corporation (AMC) and the non-governmental organization Snehalaya. The rationale for selecting this project lies in its foundation within a setting characterized by robust social connections. The deconstruction of this project's model revealed that the formulation of the design concept was grounded in three fundamental elements: (1) behavior, (2) spatial practice, and (3) atmosphere.

The primary focus of this project is to emphasize the development of a community rather than the construction of physical structures, which is achieved by placing importance on creating a harmonious blend of secure and hygienic individual and shared spaces that augment natural social connections and facilitate human growth. This project is perceived as an initiative fostering strong social cohesion and enhancing communal ties. The investigation of this project revealed that the preparation of the design concept emphasized three key elements, with the initial element being behavior. The customary practices of the individuals who originally inhabited residential properties situated on land encompassed the rearing of livestock and cultivation of vegetation. This study introduces the potential utilization of communal areas for livestock rearing and agricultural cultivation, replicating shared spaces as a viable option for these activities.

Furthermore, located at the residence's forefront, a pathway can be utilized to cultivate vegetation in a containerized growth medium. This feature enables residents to engage in activities within high-rise residential buildings consistent with their prior behavior in low-rise residential dwellings. Figure 1 below illustrates the reference reading involved in this study.

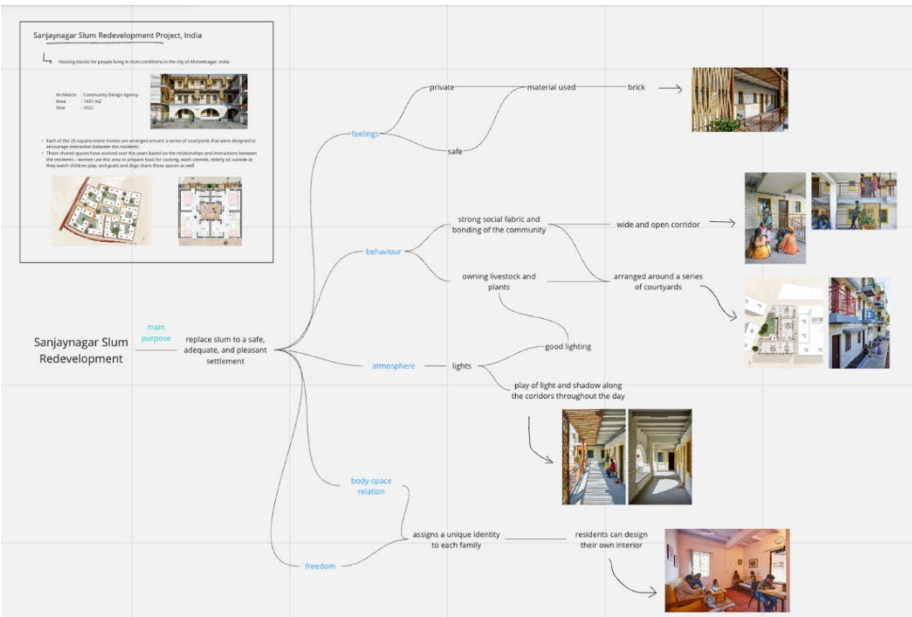


Figure 1 Reference reading the Sanjaynagar slum redevelopment project

The predominant spatial practice within this community involves using outdoor areas for communal gatherings and social engagements. The design concept incorporated a broader corridor at the front of the house, intended to serve as a communal area. Furthermore, in terms of the athmospere, two fundamental materials, bamboo, and brick, emerged as hallmarks of landed structures. These materials have been integrated into high-rise buildings to establish a congruous ambiance, albeit as supplementary constituents.

The eading reference provides a foundation for comprehending the fundamental components of memory associated with behavior, spatial cognition, and environmental context. The concept of housing extends beyond providing shelter, encompassing social services and utilities as well.

### 4.3. Compilation of Memory-Building Rules

It is crucial to identify guidelines based on prior literature queries to present an architectural concept emphasizing memory. This study explores various mechanisms to enhance memory retention in high-rise buildings, focusing on three primary keywords: behavior, spatial practice, and atmosphere. Enabling the transfer of memory from a landed building to a high-rise building involves the identification of rules that can stimulate the design.

Analyzing spatial configuration to memory entails examining the contextual factors surrounding different residential structures in urban village regions. Certain attributes about residing in an urban village within Indonesia are being considered. The idiosyncrasies of their living space encompass the diverse domestic activities that extend beyond its confines (Harani et al., 2021; Lathif, 2020; Yatmo & Atmodiwirjo, 2013). It is possible to engage in, as a group, a variety of activities more commonly performed privately or separately in the urban village area. These forms demonstrate spatial knowledge between various 'inside' and 'outside' environments.

In domestic activities within a corridor, the ownership of said corridor, which was originally designated as a public space, will temporarily transfer ownership to each occupant, limited to the boundaries of their individual residential unit. These phenomena obscure the perception of both the inside and the outside. The phenomenon of movement between the inside and the outside can be attributed to two distinct mechanisms. The first mechanism involves transferring activities from the inside to the outside and vice versa. The second mechanism pertains to transferring interior objects to the outside setting (Atmodiwirjo et al., 2015). The inside-outside relationship becomes vital in compiling the rules for developing high-rise building designs. the finding in the rules of memory is illustated in Figure 2.

The habituation of individuals in urban kampungs is characterized by a multifaceted array of elements, including bird cages, hanging plants, and pets. Providing space for planting and raising livestock is a crucial aspect of the daily routine of individuals who maintain robust social ties in these communities.

The study involved two searches, where one focused on community-based high-rise housing design references, and the other directly examined the context of landed housing in Indonesian urban *kampungs*. The findings indicate that housing residents exhibit diverse elements intrinsic to their daily lives. The presence of intricate components within a given space can lead to the utilization of pre-existing surfaces and the emergence of customary practices unique to the local populace.

These identified aspects permeate residents' daily lives in their homes. To transition from landed to high-rise residential forms, providing a novel living experience to prospective residents is imperative. The process involves transferring the experience through recollections of their former homes. The socio-spatial of everyday practices regarding this study is illustrated in Figure 3.

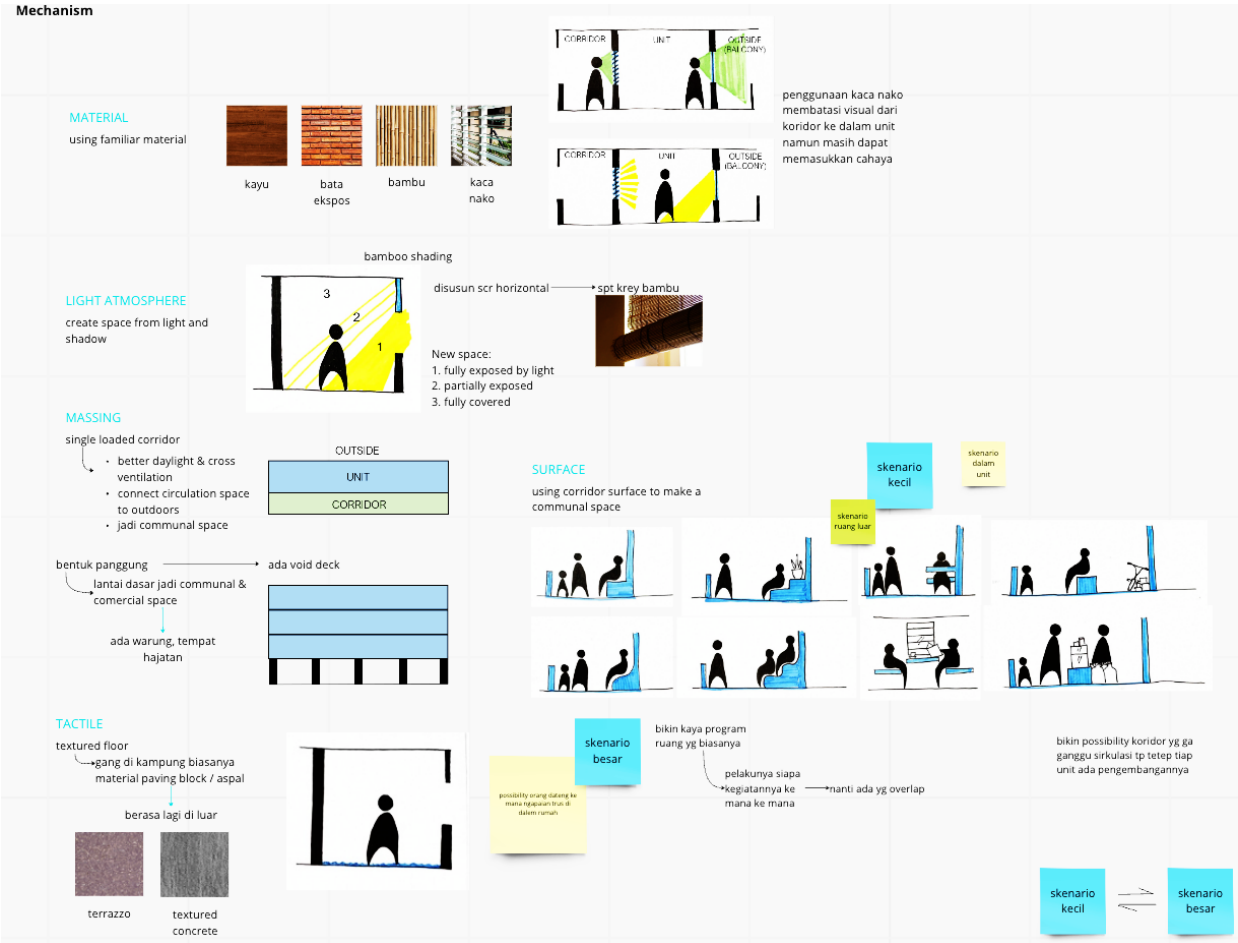


Figure 2 Finding the rules of memory

Figure 3 Socio-spatial of everyday practices

### 4.4. Bringing the Experience of Landed Residence to High-Rise through Memory

4.4.1. Spatial Settings

Strong social ties allow for increased flexibility in allocating space within a household to accommodate various activities. The use of inside-outside flexibility rules can facilitate this task. In the design of high-rise housing, the boundaries between the inside and the outside are intentionally blurred. This concept aligns with the desire of contemporary occupants to have a residence that transcends traditional definitions of interior and exterior spaces, living in the transitional space between inside and outside.

Three potential design alterations to achieve space flexibility have been identified in this context. First, residents can keep the space unobstructed, functioning as an entrance yard or balcony, serving various purposes such as a living area, relaxation space, or storage area for household items. Second, the space can be equipped with strategically placed openings to facilitate the establishment of commercial enterprises that require face-to-face engagement with customers, such as food and grocery kiosks. Third, residents can fully enclose this area with doors and windows, creating an additional enclosed space within their dwelling. The illustration of these spatial settings can be found in Figure 4 below.

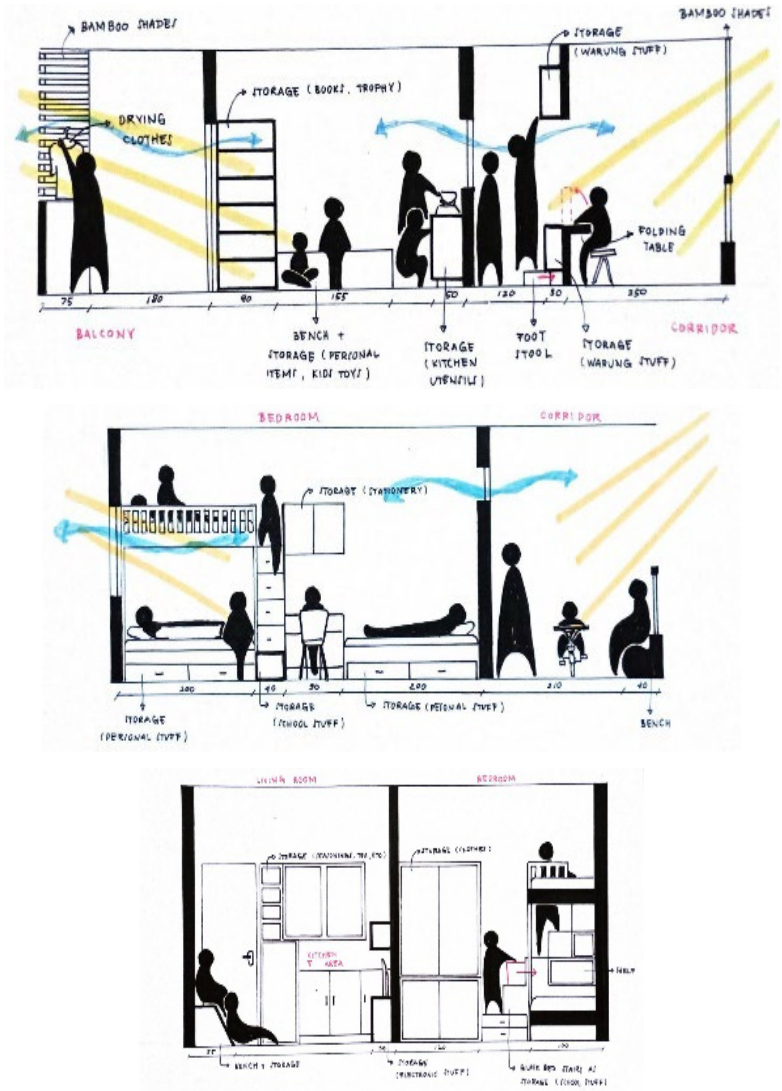


Figure 4 The possible design modifications based on spatial setting

These flexible spatial configurations allow residents to adapt their living spaces to their specific needs and preferences, creating a sense of continuity between their previous landed residence and the high-rise environment.

#### 4.4.2. Culture

The transition from landed residential houses to high-rise buildings can be facilitated by integrating consistent cultural norms, such as providing communal areas that allow residents to engage in crop planting and livestock husbandry. In traditional cultural practices associated with residing in landed housing, available space was often used for pursuing personal interests or routines, such as crop planting and livestock husbandry. It is essential to consider the integration of these practices to maintain a sense of continuity between the previous landed residence and the high-rise environment.

One approach is to allocate a designated area within the high-rise building's front hall for farming or planting. Additionally, for animal husbandry, it may be feasible to provide specific surfaces with hooks at the rear of vertical housing structures to accommodate the needs of residents.

The shared spaces near the corridors of high-rise housing can serve as storage containers for planting using containers, contributing to the enhancement of greenery within the building's vicinity. Furthermore, common areas situated at the base of the building and on the rooftop can function as platforms for residents to cultivate agricultural products. These spaces can also be used for food preparation during communal events, communal dining, or even for selling products to benefit the community.

This illustrates how cultural practices observed in traditional landed houses can be effectively transplanted into high-rise residential buildings, allowing occupants to maintain their customary way of life. These practices result in diverse spatial configurations that primarily involve alterations in elevation. The integration of cultural practices within high-rise residential buildings underscores the role of culture in shaping memory within a new dwelling, expanding the scope of memory considerations in architectural design, particularly for high-rise buildings with strong communal bonds.

#### 4.4.3. Collective Activity

Incorporating collective activities and social interactions into high-rise residential buildings is critical to preserving the sense of community often associated with traditional landed houses. To achieve this, several design considerations can be implemented:

1. Community Kitchen: It is essential to include a communal kitchen within the building to accommodate cooking habits that involve group cooking on occasions like Thanksgiving or for restaurant business purposes. Placing the kitchen at the front of the unit, directly adjacent to outdoor areas, can facilitate its functions. This approach aligns with the idea that residential unit design should not only focus on indoor spaces but also consider the potential of outdoor spaces as extensions for service activities (Yatmo & Atmodiwirjo, 2013).
2. Social interaction spaces: High levels of social interaction that were characteristic of landed-type dwellings need to be replicated in high-rise buildings. Designating areas within the building where residents can freely interact daily without disrupting the building's main functions is crucial. One effective design approach is to employ a single-loaded corridor type in each building, ensuring a sufficient width for various activities to occur within the corridor without obstructing circulation.

3. Multi-functional surfaces: The surfaces at the front of residential units and in corridors can be designed to serve multiple functions. These surfaces can be used as seating areas, places to display plants, areas for small businesses, and storage spaces. Additionally, furniture inside the units can be designed for efficiency and adaptability to different functions.
4. Communal spaces: Designing wider lift lobbies on each floor can create communal spaces suitable for collective activities such as competitions, religious gatherings, meetings, and social events. The ground floor of the building can also be left empty or designed as a communal area to accommodate larger-scale activities.

These factors highlight the feasibility of recreating memories during residents' transition to high-rise buildings by replicating the ambiance of their former residences. Regulations and design techniques can be employed to preserve memory through spatial configurations, integrating cultural practices, and emphasizing collective activities. The second design consideration involves incorporating cultural practices into existing spaces, such as utilizing them for planting and raising livestock, to present culture. The task can be accomplished through the process of media preparation and the consideration of surfaces as layers of activity. Furthermore, the emphasis on households with robust social ties results in the presence of space as a site for communal engagement, thereby underscoring the significance of collective activity, as the implementation of an interactive surface can be achieved through the utilization of a single-loaded corridor. These considerations contribute to a holistic approach to memory preservation in architectural design for high-rise residential buildings.

## 5. CONCLUSION

This study underscores the pivotal role of memory in establishing a vibrant social atmosphere when transitioning from land-based residences to high-rise buildings. As manifested through spatial arrangement, culture, and the consideration of collective activities, memory serves as a foundational framework for developing high-rise residential structures that prioritize social ties among their inhabitants. In line with Andersen's assertion (2007) that the construction of physical structures goes hand in hand with community development, this study demonstrates that community-building initiatives can be effectively implemented in high-rise residential buildings by harnessing the memories of past dwelling places.

The concept of interiority, as emphasized by Atmodiwirjo & Yatmo (2021), emerges as a crucial aspect of socio-spatial understanding, particularly in the context of memory. This is evident in the spatial arrangement, which reflects the relationship between the interior and exterior environments. Furthermore, this research highlights the importance of studying the ways of life in traditional landed houses as a foundational step in compiling design rules for high-rise residences, thus optimizing the transition process. This underscores the significance of considering the everyday practices of occupants when designing residential homes. The findings from this study have the potential to evolve into a method for designing homes that prioritize socio-cultural aspects and align with the everyday practices of the residents, in line with study done by Adianto et al. (2021).

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# INTERACTING ACTION OF ALKALI-SILICA REACTION AND CHLORIDE-INDUCED STEEL CORROSION ON THE REINFORCED CONCRETE STRUCTURES – A CRITICAL REVIEW

Williams Dunu[1*]

[1]Civil Engineering, University of Witwatersrand, Johannesburg, Gauteng, South Africa

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## ABSTRACT

The degradation of reinforced concrete (RC) structures amidst the progression of corrosion within alkali-silica reaction (ASR)-affected structures is a complex phenomenon marked by diverse causal factors and repercussions. While the initiation phase of chloride-induced steel corrosion and ASR in RC structures has received extensive scrutiny, insufficient attention has been dedicated to comprehending the propagation phase (tp). Therefore, this study addresses this gap by centering its focus on the propagation phase, driven by the imperative need to formulate efficient and sustainable maintenance, repair, and management strategies for RC structures grappling with the concurrent impacts of degradation mechanisms such as ASR and corrosion. The use of corrosion initiation for predicting the operational lifespan of RC structures has been subject to rigorous examination by researchers and engineers, especially in light of recent breakthroughs in the concrete construction industry. In this context, the present investigation presents early findings, employing durability index tests to analyze the durability attributes of concrete incorporating both reactive and non-reactive materials (aggregates). Furthermore, the study proposes enhancements to prior research endeavors in this domain. While additional data is requisite to ascertain the cumulative influence of ASR and corrosion, conducting a comparative analysis of fluid transport rates through ASR-susceptible and ASR-non-susceptible concretes offers valuable insights into the maintenance and restoration of RC structures afflicted by both corrosion and ASR.

Keywords: Alkali-silica reaction; Chloride-induced steel corrosion; Durability performance; Reinforced concrete structures; Transport properties

## 1. INTRODUCTION

Chloride-induced corrosion, an electrochemical process at the steel-concrete interface, significantly accelerates the deterioration of reinforced concrete (RC). Driven by the ingress of hazardous species into concrete, it expands hygroscopic corrosion products and consequently causes concrete cover cracking structures (Angst et al., 2011). In varius studies (Enevoldsen et al., 1994; Gouda, 1970; Otieno & Alexander, 2010; Tuutti, 1982; Mehta, 2008), the degradation process is commonly divided into two phases: initiation and propagation (see Figure 1).

Before corrosion initiation, the initial stage exhibits minimal to negligible detrimental effects. However, the ingress of hazardous substances such as chlorides can penetrate the concrete to the steel reinforcement surface, resulting in the degradation of its protective coating and subsequent corrosion.

*Corresponding author's email: msc8083dunu@gmail.com
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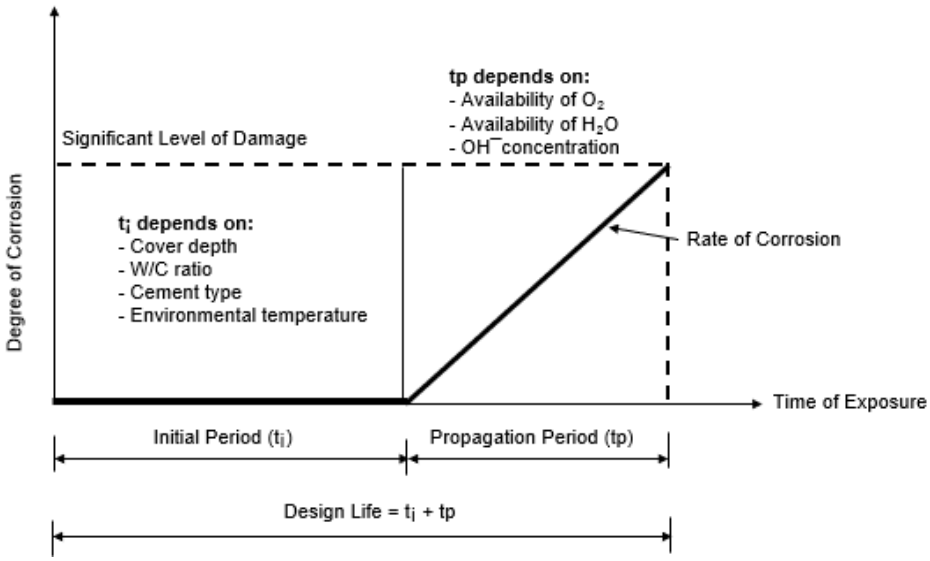


Figure 1: Corrosion initiation and propagation phases (Otieno & Alexander, 2010).

According to Beushausen et al. (2012), the infiltration of hazardous substances, as well as the advancement of chloride ingress, is primarily influenced by the concrete's quality in terms of its penetrability, the chemical composition of the pore solution, the prevailing environmental conditions, the thickness of the concrete cover, and the probability of concrete cracking.

During the subsequent phase, known as corrosion propagation, the process of corrosion activation leads to the formation of corrosion products. These products subsequently undergo expansion, resulting in cracks within the cover concrete. The primary factors contributing to this phenomenon are the interplay between oxygen and chloride transport, the chemical composition of the pore solution, and the prevailing temperature conditions. In the context of reinforced concrete exposed to externally aggressive ions, the effectiveness of the cover in preventing the ingress of hazardous compounds assumes significant importance.

The phenomenon of alkali-aggregate reaction (AAR) can be categorized into two distinct mechanisms, namely alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). The formation of ASR, as detailed in studies by Attar et al., (2020) and Gorga et al., (2022), results from a chemical reaction between alkali in the concrete pore solution and reactive minerals in the aggregate (Fournier & Bérubé, 2000). Concurrently, ASR poses another threat to the structural integrity of RC structures. Furthermore, ASR is the prevailing mechanism observed in concrete structures. The development of ASR necessitates the presence of three key components: an aggregate comprising reactive mineral phases, a high moisture level typically exceeding 85%, and a high alkali concentration. This reaction produces an expansive gel, leading to structural damage.

According to Gautam and Panesar (2017), enhancing durability necessitates the capacity to quantify the fundamental determinants of durability with utmost clarity and precision. This study aims to bridge the gap in understanding the interplay between chloride-induced corrosion and ASR in RC structures. While traditional quality control tests have focused on concrete strength, they must address durability concerns. Our research critically examines the durability index test, which assesses material resistance to degradation agents ($Cl^-$, $H_2O$, and $O_2$), which is fundamental in steel corrosion and ASR. By analyzing existing literature and conducting an ongoing investigation, we seek to understand the combined effects of these two degradation processes on RC structures. Our goal is to offer insights for developing more effective maintenance and repair strategies, enhancing the durability and longevity of RC infrastructures.

## 2. LITERATURE ON THE CHLORIDE-INDUCED STEEL CORROSION AND ALKALI-SILICA REACTION IN REINFORCED CONCRETE STRUCTURES

Research on RC structures traditionally focuses on damage caused by ASR or chloride-induced corrosion (Michel et al., 2016; Otieno et al., 2016; Karthik et al., 2018; Giaccio et al., 2019), but Trejo et al. (2017) highlight, the combined effects of these two degradation mechanisms still need to be fully understood, particularly in environments like marine settings where both are prevalent. In a marine environment, RC structures can have alkali-silica reactions and be subject to corrosive conditions (chloride-induced corrosion). So, it is important to know how the activities of the degradation processes work together to affect the durability of RC structures.

Studies (Yu et al., 2015; Otieno et al., 2010; Francois and Arliguie, 1998) have demonstrated that aggressive agents can reach steel reinforcement through cracks in RC, which ASR often exacerbates. This suggests a synergistic effect where ASR can accelerate chloride transport, potentially hastening the onset of active corrosion. The challenge remains to quantify how these combined effects influence the longevity of RC structures, a crucial aspect for those working with concrete in developing durable infrastructures.

There are three existing research on the combined effect of chloride-induced steel corrosion and ASR reviewed in thi study, including study by Mitsunori et al. (1989), Trejo et al. (2017), and Wang & Sugiyama (2022).

### 3.1 Mitsunori et al. (1989)

Mitsunori et al. (1989) focused on how ASR affects steel corrosion in chloride-contaminated mortar. The experiment was conducted with 40 × 40 × 160 milimeters (mm) mortar specimens made from regular Portland cement containing 0.93% $Na_2O$ equivalent. Beltane opal aggregate with sizes ranging from 1.2 mm to 0.6 mm was employed as a reactive aggregate. A non-reactive aggregate of Toyoura siliceous sand was also employed. Mortars were produced using a water-to-cement ratio of 0.5. Reactive aggregate was used to replace 3% of the overall aggregate. Sodium chloride was pre-dissolved in the combined water of mortar specimens in amounts equal to chloride ion addition levels of 0.25, 0.5, 1.0, and 2.0% by weight of cement. Mortar cylinders 5.6 cm × 10 cm for pore solution expression were kept at 38°C in sealed vinyl bags within a fog box. After a predetermined curing time, the high-pressure equipment extracted pore solutions from mortar samples. Chloride ion concentrations were determined using coulometric titration. In addition, the hydroxyl ion concentration of the extracted solutions was measured using a phenolphthalein endpoint titration with hydrochloric acid. Mortar sample length differences were measured. The mortar samples were fitted with a mild steel electrode and a stainless-steel counter electrode, and the corrosion intensities of the steel electrodes were measured using polarization resistance. The electrochemical test was carried out on specimens kept at 38°C in a fog box. For over a month, duplicate specimens were measured every day, then every two days. The following conclusions were drawn from the study:

- Mortar specimens containing reactive aggregate experience more expansion than reactive aggregate-free mortar specimens.
- The addition of the reactive aggregate accelerated the corrosion of steel embedded in reactive aggregate mortars due to some changes in the microstructure of the mortar phase brought on by the alkali-silica reactions (i.e., cracks).
- The measured $Cl^-/OH^-$ ratios in pore solutions extracted from mortars containing the reactive aggregate are greater than those without the reactive aggregate at a given chloride ion addition amount.

### 3.2 Trejo et al. (2017)

Furthermore, Trejo et al. (2017) explored the impact of ASR on chloride transport and corrosion initiation. They used reactive and non-reactive aggregates in their specimens and observed expansion and cracking in those containing reactive aggregates. The specimens were designed following the general specifications (ASTM C1293, 2008). As anticipated, certain specifications and criteria have been adjusted to satisfy the aims of this study. Ten 285 x 152 x 114 mm specimens were manufactured and evaluated. Utilized were a non-reactive limestone coarse aggregate, a non-reactive limestone fine aggregate, and a highly reactive natural siliceous river sand. Prior to this work, the reactivity of these aggregates was validated using (ASTM C1260, 2010). Five samples included fine aggregate that was reactive, while five contained fine aggregate that was non-reactive. All samples had coarse aggregate that was non-reactive. The specimens were strengthened with 285 mm-long pieces of reinforcing bars. Each end of the steel reinforcement was covered with electroplating tape, revealing the 200 mm test section. In order to determine the length change of the specimens, two-gauge studs were inserted in the concrete at each end of the specimens. As required by ASTM C1293, sodium hydroxide was added to the concrete mixing water to enhance the alkali content to 1.25% $Na_2O_{eq}$ by cement mass.

A water-cement ratio (w/c) of 0.45 was utilized for all specimens. After curing, the specimens were exposed to 100°F (38°C) and 95% RH. Specimens were exposed for two weeks to a 3% sodium chloride (NaCl) solution ponded on the specimen's surface. In addition to being ponded, specimens were housed in plastic containers with airtight lids. This was done to maintain a high RH and encourage ASR. The bottoms of the containers were filled with water. As specified by ASTM C1293, a plastic rack was inserted in the bottom of the containers to elevate the specimens above the water. After demolding, the first expansion of the specimens was measured (24 hours after casting). Comparator readings were taken one and four weeks following the original reading and, after that, monthly until the initiation of corrosion. The subsequent findings were reached:

- The formation of ASR gel in specimens containing a reactive fine aggregate resulted in expansion and cracking of the specimens containing reactive aggregate, but this was not observed in the specimens containing non-reactive aggregate.
- The specimens containing reactive and non-reactive aggregate showed similar times to corrosion initiation.
- Specimens containing non-reactive aggregate exhibited a higher corrosion rate than those containing reactive aggregate. This indicates that ASR resists the transport of chlorides, and the presence of ASR gel can act as a barrier against chloride transport in concrete, resulting in a lower overall penetration rate of the chlorides.

### 3.3 Wang & Sugiyama (2022)

Study by Wang and Sugiyama (2022) investigated steel corrosion in steam-cured concrete under simultaneous chloride attack and ASR. They employed various concrete mixes, aggregates, and testing methods to evaluate expansion rates, corrosion risks, and chloride diffusion coefficients. Figure 2 shows prismatic concrete examples of 100 mm in width, 300 mm in length, and 128 mm in height constructed in this work. Two deformed steel bars with a 19 mm diameter were placed in parallel on each specimen at 30 mm concrete thickness intervals along the height direction. The following concrete mix proportions are marked: H (100% PC) with no reactive aggregate, HA (100% PC) with reactive aggregate, FB (80/20 PC/FA) without reactive aggregate, FBA (80/20 PC/FA) with reactive aggregate, and BB (50/50 PC/SL) without reactive aggregate. The water-to-binder ratio in SCM-containing concrete (FA and SL) was 0.35, compared to 0.40 in 100% PC examples (H and HA). The HA and FBA coarse aggregate comprised 30% active alkali

andesite and 70% limestone. The most reactive andesite comprises tridymite, cristobalite, volcanic glass, and micro secondary quartz.

To accelerate ASR, the total alkali content of HA and FBA concrete was increased to 5.5kg/m3 using a sodium hydroxide reagent. All specimens in this study were subjected to 24 hours of steam curing following casting. The heating rate was kept constant at 15°C per hour during steam curing, and the maximum temperature reached 60°C for four hours. Specimens H, FB, and BB were cured at 20 ±2°C in a temperature-controlled chamber. Water curing of HA and FBA was followed by air curing in a typical setting. The specimens were subjected to length variation testing. In contrast, the half-cell potential approach (using a lead/lead sulfate reference electrode) was utilized to evaluate the electrochemical reaction process at the steel/concrete contact in the chloride penetration test. After the experiment, the following conclusions were drawn from the findings.

- During the first five weeks of the accelerated length change test, the expansion rate of HA concrete with the pessimum proportion of reactive andesite aggregates was 0.133%. Adding fly ash to FBA concrete reduced but did not eliminate the expanding behavior caused by ASR.
- Even when the reference electrode (RE) was positioned on the bottom surface of the concretes, the upper rebar's corrosion was accurately identified using the specimen half-cell potential tests. As a result, the half-cell potential test is appropriate for high-strength, steam-cured concrete with a thick cover, such as a real concrete bridge slab.
- According to the overall trend of the specimens, all specimens with reactive aggregate exhibited a higher risk of embedded reinforcement corrosion than specimens without reactive aggregate. Reactive aggregate specimens have a lower (more negative) half-cell potential than non-reactive aggregate specimens. The HA (100% PC) half-cell potential with reactive aggregate exhibited the highest corrosion chance (greater negative value). This reveals that sodium chloride penetration causes early rebar de-passivation in HA due to the combined effects of ASR and chloride intrusion.
- The chloride diffusion coefficients of H and HA concrete were $47.9\times10^{-12}$ $m^2$ /s and $63.4\times10^{-12}$ $m^2$ /s, respectively. On the other hand, the chloride diffusion coefficients of FA and BB concrete were $1.0\times10^{-12}$ and $0.9\times10^{-12}$ $m^2$ /s, respectively. This demonstrates that using fly ash and blast furnace slag for corrosion prevention of reinforcements in high-strength steam-cured concrete is successful.

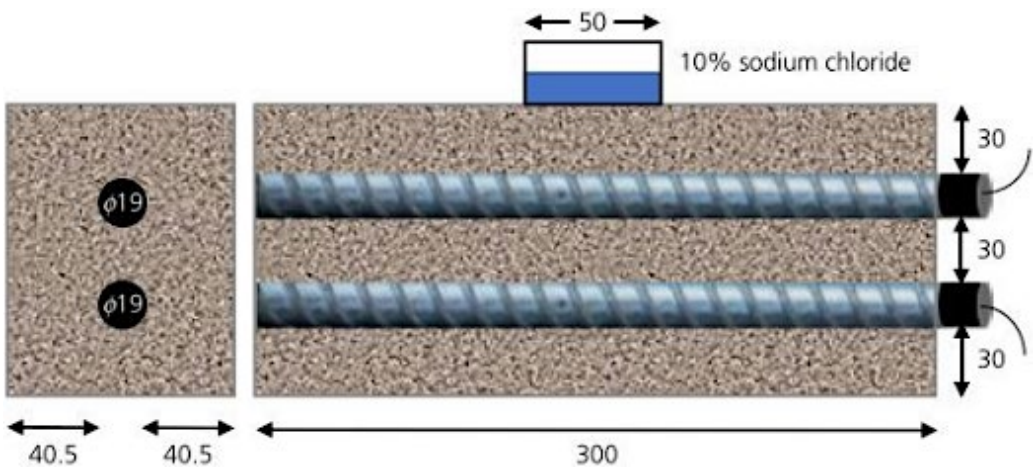

Figure 2. Schematic representation of the specimen set-up (Wang & Sugiyama, 2022)

## 3. DISCUSSION AND CRITIQUE OF THE EXIXTING STUDIES

### 3.1 Discussion of the Existing Study's Findings

The intricate interplay between ASR and chloride-induced corrosion within RC structures has garnered considerable individual attention in previous research. However, the amalgamation of these two degradation mechanisms poses a multifaceted challenge, necessitating further investigation to comprehensively understand their combined effects on steel corrosion in RC structures. Previous studies have predominantly focused on corrosion initiation, employing various assessment procedures and methodologies to explore the intricate interaction between ASR and chloride-induced corrosion. Notably, the research by Mitsunori et al. (1989) and Wang & Sugiyama (2022) revealed a consistent trend, indicating that concrete specimens containing reactive aggregate (ASR-susceptible) exhibited a higher susceptibility to steel corrosion when exposed to chloride solutions compared to specimens with non-reactive aggregate (not susceptible to ASR). This susceptibility was attributed to alterations in the concrete microstructure induced by ASR, including the formation of cracks and detachment of aggregate from the cement paste matrix, which facilitated the ingress of chloride ions to the steel surface. Furthermore, the alkali-silica reaction in concrete led to a lower hydroxyl (OH-) to chloride ions (Cl-) ratio in the pore solution, promoting corrosion due to an elevated concentration of Cl- ions.

The findings of Trejo et al. (2017) contradicted those of Mitsunori et al. and Wang & Sugiyama. Trejo's study suggested that the initiation of corrosion occurred concurrently in specimens containing reactive aggregate and those without reactive aggregate. During the monitoring period, the corrosion status of specimens with reactive aggregate improved relative to those without reactive aggregate. This divergence in results may be attributed to the disparate methodologies employed by each research group. Trejo's experiment involved maintaining specimens at high humidity and elevated temperature without a drying cycle, which may have saturated the specimens and limited the availability of oxygen at the steel surface, hindering the cathodic reaction essential for corrosion. In contrast, other researchers introduced wetting (Polder & Peelen, 2002; Wu et al., 2016; Ye et al., 2016) as well as drying cycles (Otieno et al., 2016; Malumbela, 2010; Otieno et al., 2010; Scott & Alexander, 2007), which facilitate chloride penetration through capillary suction during wetting and replenishing dissolved oxygen at the steel surface during drying, thereby promoting the corrosion process. Moreover, air-drying or drying at elevated temperatures can be achieved through the concrete specimens' drying phase (Yuan et al., 2008; Scott & Alexander, 2007). These variations in experimental conditions underscore the need for a comprehensive examination of ASR and chloride-induced corrosion interactions in RC structures, considering diverse environmental factors and methodologies.

### 3.2. Critique to Existing Combined Action of the Deterioration Mechanisms

Studies focusing on the initiation phase of corrosion, such as those by (Mazarei et al., 2017; Mitsunori et al., 1989; Trejo et al., 2017; Wang & Sugiyama, 2022), and others, have been instrumental in understanding the early stages of RC degradation. However, as Jung et al. (2003) and Otieno & Alexander (2010) assert, this focus might underestimate the actual service life of structures. As a result, it has become critical to measure corrosion propagation and structure performance carefully during this time. However, according to a recent assessment of the relevant research (El Maaddawy & Soudki, 2007; Zhang et al., 2009; Otieno & Alexander, 2010), the emphasis is on propagation duration. The following factors could have contributed to this shift in perspective:

- Making a structure last longer than its original service life is usually described as the end of the initiation phase.

- There are already a lot of RC structures in the propagation stage that need to be fixed. You must know much about corrosion processes to make correct predictions and diagnoses.
- The need to forecast the performance of new structures in conditions prone to alkali-silica reactions in corrosive environments (marine environment). If this is achieved, effective repair and maintenance management strategies can be developed to ensure timely and optimal intervention.

Moreover, the existing studies on the combined action of the deterioration mechanisms (corrosion and ASR) had not distinguished between concrete specimens containing reactive aggregate and those containing non-reactive aggregate. In the context of this paper, the prospective durability of concrete is defined as the cover concrete's resistance to chloride conduction, oxygen permeation, and water absorption. This paper will thus present preliminary results from durability index tests, contributing to the broader discourse on RC structure longevity in corrosive and ASR-prone environments, and characterize the concrete matrix of the specimens as a basis for comparison using durability parameters (Cl-, $H_2O$, and $O_2$).

## 4. FUTURE OUTLOOK: AN ONGOING STUDY

The current investigation of the deterioration of RC structures due to alkali-silica interactions and chloride-induced steel corrosion inspired the review presented in this paper. This ongoing study aims to understand the corrosion propagation phase of structures that display alkali-silica interaction and are exposed to corrosive circumstances (chloride-induced steel corrosion); this will aid in developing proactive maintenance and repair techniques. Moreover, it is necessary to highlight the necessity to address some of the inadequacies of the existing studies described in this work. In the next part, a synopsis of the preliminary results of the durability index test of the research is offered.

### 4.1. Objectives and Expected Outcomes of the Ongoing Study

The primary goal is to assess the impact of both ASR and chloride-induced corrosion on the durability of RC structures. This involves conducting corrosion assessment experiments on specimens with and without reactive aggregate, encompassing corrosion initiation and propagation phases. Key aspects of this study include analyzing the influence of different aggregate types (reactive and non-reactive) on concrete structures, with durability performance evaluated through chloride conductivity, oxygen permeability, and water sorptivity tests. Furthermore, to account for the inherent variability of corrosion rate, an analysis will be performed on the corrosion-influencing parameters of aggregate types (reactive aggregate and non-reactive aggregate) and concrete quality of binder types (OPC, slag, and fly ash).

It is anticipated that, upon completion of the study and achievement of the objectives above, the following outcomes will be realized:

- Recommendations for proactive conservation (maintenance and repair) strategies to enhance or extend the initial design service life, focusing particularly on the corrosion propagation phase.
- The durability performance of concrete structures under the combined action of the degradation mechanisms (corrosion and ASR) will be measured using measurable metrics such as durability index tests (oxygen permeability index, water sorptivity index, and chloride conductivity index). In addition, corrosion and ASR assessment tests (corrosion rate, concrete resistivity, and corrosion potential, while longitudinal and transverse expansion of concrete specimens due to ASR will be utilized to determine the performance of the structures.

Figure 3 outlines the experimental work plan detailing the methodology used for assessing the deterioration of RC structures under the combined effects of chloride-induced steel corrosion and ASR. The experiments are divided into two parts: one focuses on corrosion assessment and monitoring, and the other employs tests like ASTM C 1260, ASTM 1293, compressive strength, and durability index tests for ASR measurement.

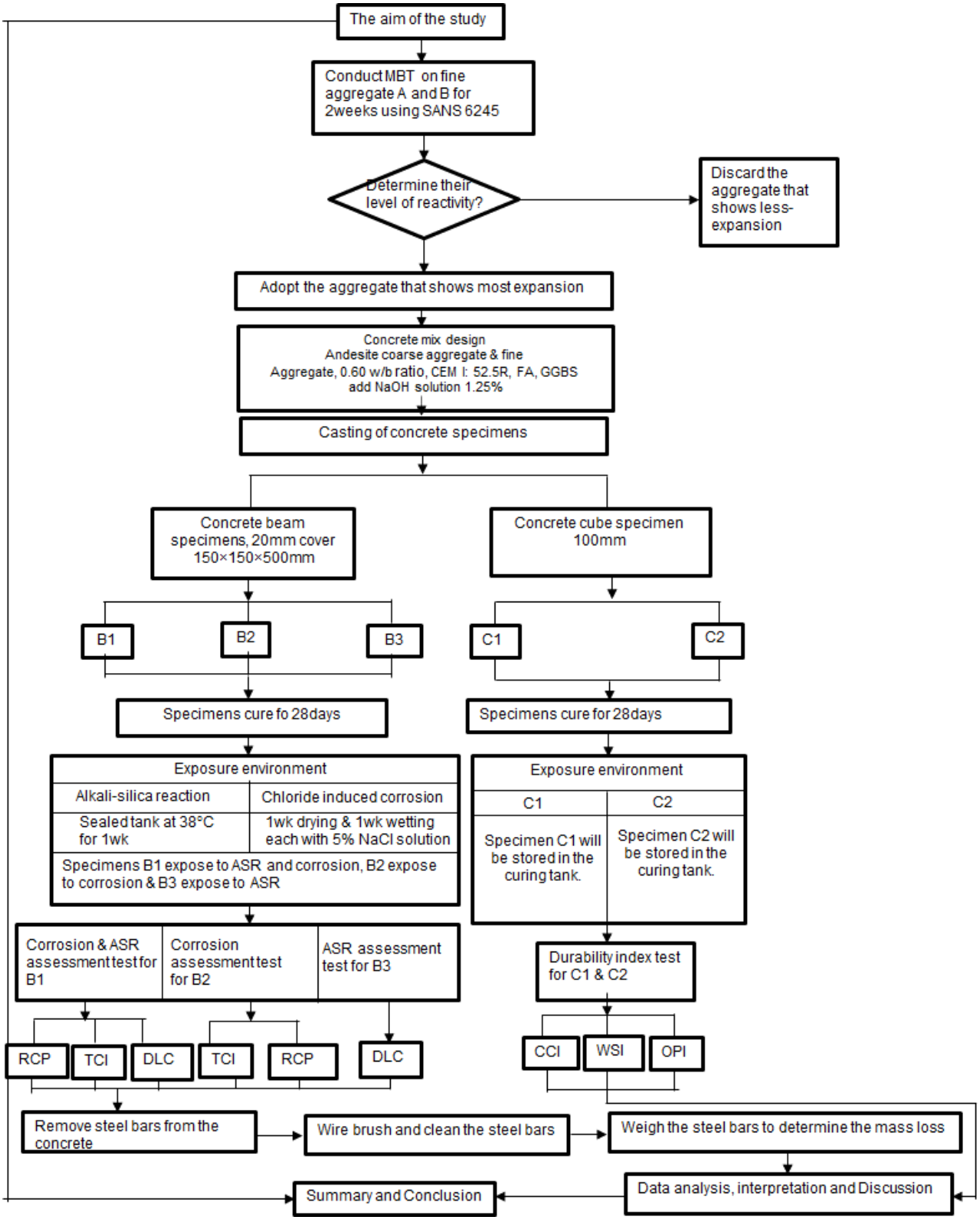


Figure 3. Research methodology flow chart

Legend:
ASR : Alkali-Silica Reaction
B1 : Beam specimen (corrosion scenario)
B2 : Beam specimen (alkali-silica scenario)
B3 : Beam specimen combined (corrosion and ASR) scenario
C1 : Cube specimen containing reactive aggregate
C2 : Cube specimen containing non-reactive aggregate
CCI : Chloride conductivity index
DLC : Dimensional length change
FA : Fly ash
MBT : Mortar bar test
OPI : Oxygen Permeability Index
RCP : Rate of Corrosion Propagation
TCI : Time of Corrosion Initiation
w/b : Water-to-binder ratio
WSI : Water Sorptivity Index

The following sections present the preliminary results of the durability index test conducted in this ongoing study.

### 4.2. Experimental Set Up

This ongoing study involves a comprehensive experimental set-up to evaluate the durability of concrete structures subjected to the combined effects of ASR and chloride-induced steel corrosion. Utilizing both reactive and non-reactive aggregates, the concrete specimens were subjected to three critical durability index tests: the OPI, WSI, and CCI. Concrete quality was assessed in two categories based on aggregate reactivity. 'Reactive aggregate' specimens, susceptible to ASR, used Sub-Nigel crushed aggregate, while 'non-reactive aggregate' specimens employed Andesite crushed aggregate. The study encompassed various concrete mixes using slag (SL), fly ash (FA), and Portland cement (PC), each with reactive (R) and non-reactive (NR) variants. The sample notations employed in the presentation of the experimental data in this paper are as follows:

a. PC-NR; for 100% Portland cement beam specimen containing non-reactive fine and coarse aggregate.
b. PC-R; for 100% Portland cement beam specimen containing fine reactive aggregate and non-reactive coarse aggregate.
c. 50/50 PC/SL blend-NR for Portland cement/slag beam specimen containing non-reactive fine and coarse aggregate.
d. 50/50 PC/SL blend-R for Portland cement/slag beam specimen containing fine reactive aggregate and non-reactive coarse aggregate
e. 70/30 PC/FA blend-NR; for Portland cement/fly ash beam specimen containing non-reactive fine and coarse aggregate.
f. 70/30 PC/FA blend-R for Portland cement/fly ash specimen containing fine reactive aggregate and non-reactive coarse aggregate. The R and NR, respectively, represent reactive and non-reactive.

After allowing the concrete cubes to cure for a specific time of 28 ± 3 days, in accordance with the instructions provided in the durability manual (SANS 300-CO3-1, 2015; SANS 300-CO3-2, 2015; SANS 3001-CO3-3, 2015; Alexander, 2018), tests to determine the concrete's durability index were performed to evaluate the initial quality of the concrete and determine its prospective durability by examining how fluids, such as gasses, ions, and water, can move through the concrete cover. More precisely, the tests were conducted to quantify the extent to which

corrosion-related substances, including oxygen (O2), chloride ions (Cl-), and water (H2O), can infiltrate the concrete.

As illustrated in Figure 4, discs with a diameter of 70 ± 2 mm and a thickness of 30 ±2 mm were removed from 100 mm concrete cube specimens and subjected to durability index testing. One set of specimens was made with fine reactive and non-reactive coarse aggregates; another set of specimens was produced with non-reactive fine and coarse aggregates were used to investigate the effect of ASR on the durability properties of concrete structures.

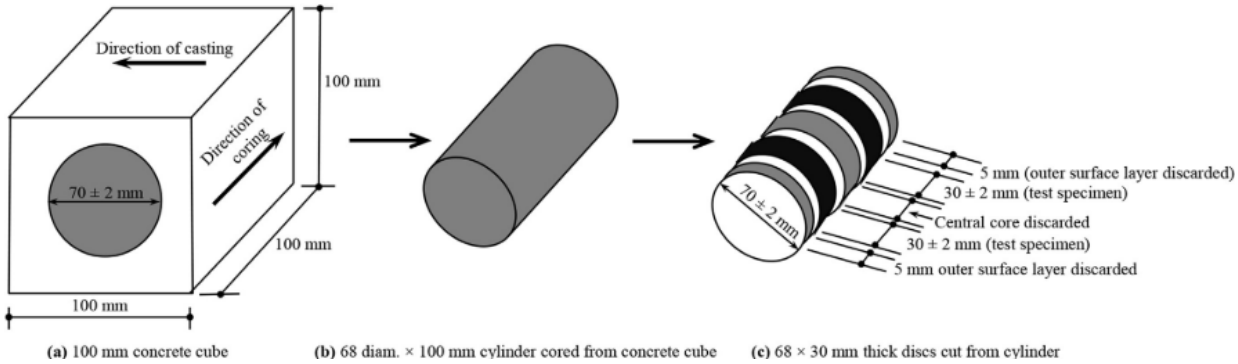


Figure 4. Durability index test disc extraction from 100 mm concrete cube (extracted discs shown in the photo were sourced from SANS 3001-CO3-1:2015; Otieno, 2018)

Evaluating the ability of the concrete cover to withstand the penetration of corrosive substances such as chlorides, oxygen, and moisture is essential in determining its effectiveness as a protective barrier. To assess the prospective durability performance, the durability index (DI) parameters, which consisted of OPI, WSI, and CCI were analyzed. This analysis was conducted on damp concrete that was subjected to a 28-day period. The subsequent results, displayed in Table 1 and depicted in Figure 5, offer understanding into the vulnerability of the concrete to substances that cause corrosion. This finding contributes to a thorough assessment of the concrete's quality in relation to potential risks posed by these substances.

Table 1: Durability Index Test Results at 28 Ddays

| Test | PC-NR | PC-R | PC/SL-NR | PC/SL-R | PC/FA-NR | PC/FA-R |
|---|---|---|---|---|---|---|
| OPI | 8.67 | 6.99 | 9.13 | 7.91 | 8.99 | 7.27 |
| WSI ($mm\sqrt{hr^{0.5}}$) | 15.10 | 31.32 | 12.15 | 16.45 | 13.86 | 23.75 |
| Porosity (%) | 12.10 | 20.70 | 10.46 | 12.78 | 10.90 | 14.07 |
| CCI (mS/cm) | 1.91 | 2.28 | 0.50 | 0.77 | 1.40 | 2.03 |
| Porosity (%) | 6.12 | 7.85 | 4.90 | 4.97 | 5.02 | 6.09 |

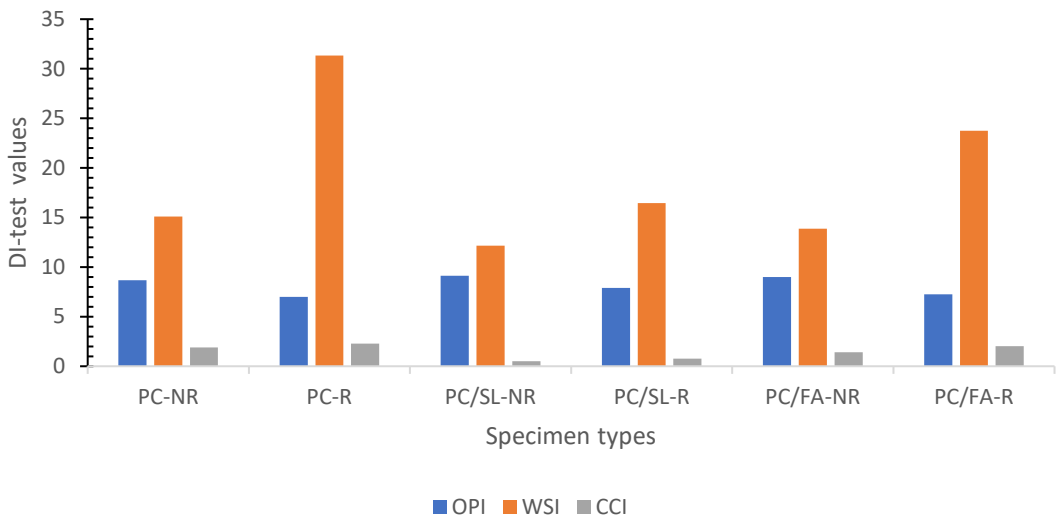


Figure 5: Durability index test results at 28 days

The general trend of the durability index test results for concrete specimens with reactive aggregate and those with non-reactive aggregate indicated that concrete made with non-reactive aggregate is of higher quality. Also, the specimens made with supplementary cementitious materials (SCMs) (i.e., FA and SL) show a higher resistance against the aggressive agents than those made with PC for both reactive and non-reactive aggregate scenarios. The following cause could have contributed to this trend.

A previous study on the determination of different aggregate reactivity indicated that reactive quartz aggregate began exhibiting void formation as a symptom of alkali-silica reaction at 28 days due to the constant moisture supply (Cruz Carlos et al., 2004). This reason was adopted because the reactive aggregate used in this study is composed of quartz, and the concrete cubes were cured in water for 28 days, which served as a constant supply of moisture to the concrete specimens. ASR causes voids and detachment at the cement paste–aggregate boundary, thereby increasing the mortar's overall porosity (Marinoni et al., 2015). The impact of the SCM specimen can be attributed to the advantageous effect of pore refinement in the paste portion of the concrete, which decreases the diffusion rate of species into the concrete (Nikam & Tambvekar, 2003).

## 5. CONCLUSION

This study critically evaluates the intricate interplay between alkali-silica reaction (ASR) and chloride-induced steel corrosion in reinforced concrete (RC) structures, along with preliminary findings from durability index tests on concrete specimens. This investigation highlights gaps in existing research and presents new insights into the combined degradation mechanisms. From this study, there are five key conclusions are drawn, which include (1) The corrosion rate is crucial in assessing corrosion-induced damage in concrete structures. Accurate evaluation of this rate is essential for structures vulnerable to ASR and corrosion; (2) Understanding the combined effects of ASR and corrosion is vital for the effective repair and maintenance of RC structures. A comprehensive grasp of these deterioration mechanisms is necessary for developing robust; (3) Current studies predominantly focus on the initiation phase of corrosion. Concrete professionals require detailed information encompassing the initiation and propagation phases to prevent misleading assessments, emphasizing key measurable parameters; (4) Enhancing durability involves precise measurement of key parameters, particularly those describing the quality of the

concrete cover layer. Traditional strength parameters are insufficient; a broader approach, such as durability index tests, is crucial for a holistic understanding of concrete deterioration; (5) The practical application of index tests for quality control must be evaluated based on the long-term durability performance of constructed structures. This necessitates a commitment to ongoing, extensive research. These conclusions underscore the importance of a nuanced understanding of ASR and chloride-induced corrosion in RC structures. The study advocates for a shift in the current research focus, urging the incorporation of comprehensive durability assessments in concrete structure analysis.

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# CREATING INTERCONNECTED OUTDOOR GREEN INFRASTRUCTURE IN THE CASE OF AKSUM HISTORICAL SITES, ETHIOPIA

Guesh Hagos Gebru[1, *]

[1]Urban Design, Adigrat University, 7040, Ethiopia

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## ABSTRACT

This study investigates the state of outdoor green infrastructures (GI) in Aksum, Ethiopia, employing qualitative and quantitative approaches to address the disconnect between the expanding urban fabric and sustainable green space development. Sentinel satellite imagery and public perception surveys revealed a fragmented landscape of green spaces, including underdeveloped areas like heritage sites, cemeteries, churches, public spaces, stream fronts, and roadside spaces. Quantitative analysis using the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI) indicated limited healthy vegetation and a built environment predominance. NDVI values ranged from +0.1 to +0.5, suggesting the presence of grass and shrubs, while NDBI results varied between 0 and 0.252, reflecting low vegetative cover. Furthermore, the Built-Up (BU) index in residential zones ranged from -0.644 to +0.128, underscoring the poor condition of GIs and their lack of interconnectivity. Addressing these issues, the research proposes a conceptual design for an interconnected GI, integrating various urban spaces into a cohesive green network. This design aims to remedy the fragmentation and enhance the environmental, social, and economic aspects of urban life in Aksum.

*Keywords*: Built up creating; Green infrastructure; Heritage site; Interconnected; Normalized difference; Vegetation index

## 1. INTRODUCTION

The concept of Green Infrastructure (GI) has increasingly become vital in shaping urban communities' political, social, and environmental fabric. This study focuses on the critical role of GI in fostering sustainable urban development, particularly in the context of Aksum, Ethiopia, an area undergoing rapid urbanization. Multicultural societies and groups worldwide have developed different spheres of knowledge about GI use and design (Hernández-Bonilla, 2008). People's ideas about GI depends on urban citizens' healthy psychological, political, and social connectedness. Accessibility to GI is linked to positive outcomes for people. Many recent descriptions of urban sustainability have now emerged to facilitate equitable, accessible, sustainable GI at all levels of urban boundaries (Gelan & Girma, 2021). GI's importance lies in its ability to create pedestrian-friendly environments that enhance social and ecological connectivity. Such infrastructures play a pivotal role in addressing urban citizens' psychological and social well-being, contributing significantly to the overall sustainability of cities.

GIs, the open spaces, are planned in the hierarchy of their requirement. The logical order is from the local up to the community park (Ghofrani et al., 2017). Providers of street services and waiting

*Corresponding author's email: gueshhg14@gmail.com
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for friends may be local initiatives and private organizations. The governments of cities have devoted themselves to showing their effort by creating representative GIs near their palace. They provide the three pillars of sustainability, solving ecological, economic, and social issues simultaneously. In addition, GIs are designed for political means (Furholt et al., 2020).

This paper explores GI's current state in Aksum and its implications for urban planning and community well-being. The extent to which existing GI meets the needs of the growing population and how it contributes to the three pillars of sustainability: ecological, economic, and social, were examined. Despite the recognized importance of GI, many urban areas, including Aksum, face challenges in developing interconnected and sustainable green spaces. This study addresses these challenges by proposing a framework for integrated GI planning, emphasizing the need for a hierarchy of green spaces ranging from local to community parks. This study's approach combines theoretical insights with practical considerations to contribute to the broader discourse on urban sustainability and GI development. Therefore, this research aims to explore the topic using the following objectives:

1. Assess the quality of outdoor green infrastructures in the historical site of Aksum Town.
2. Investigate the users' perceptions of changing the outdoor green infrastructures into interconnected nature.
3. Integrate outdoor green infrastructures among themselves and with other existing infrastructures.

Previous studies ignore the possibilities of assessing all the options of green on street/roadside green, median green, and inside backyards of big institutions. They did not specify based on accurate images and inter and intra relationship of each green space. The objective analysis of the entire green network is not assessed. Furthermore, it does not show the interconnection of mitigating solutions that have immediate advantages for planners and designers (Assaye et al., 2017). Assessing the gap in the design of GI and the creation of an interconnected whole green network gives new insight for further developers and municipality designers. The new approach to GI creates a balance of nature conservation and sustainability for the users.

## 2. LITERATURE STUDY

### 2.1. The Design of Green Infrastructure

GI forms a critical network of interconnected green spaces and water bodies, seamlessly integrated within urban landscapes and extending into rural areas. This network encompasses diverse spaces – natural, semi-natural, and artificial – each contributing multifunctionally to the community's well-being. Such infrastructures aim to deliver comprehensive benefits: environmental protection, social enrichment, and health enhancement, as highlighted by Allen et al. (2012). In the urban context, green spaces represent distinct segments of land allocated for recreation or vegetative purposes. The concept of Sustainable Green Space is pivotal, denoting areas that serve current generations and are preserved for future use. Central to this sustainability are the principles of minimizing environmental waste and adopting ecological thinking, as discussed (Shmelev & Shmeleva, 2009).

Furthermore, GI is characterized as a system comprising both man-made assets and ecosystem services dedicated to preserving and restoring nature. A holistic approach to GI planning fosters an interconnected Green Network, transcending the traditional benefits of isolated green spaces. Interconnected Green Network interwoven into the multifaceted aspects of human life, offers greater collective benefits. The effectiveness of this network hinges on three integral components: sites, hubs, and links. Sites encompass various amenities, such as hospitals, universities, and

individual plots. Hubs, conversely, are significant spaces serving as origin or destination points for species, doubling as centers for diverse activities, including work, recreation, and open-air events. Links, comprising linear elements along roads, landscapes, or riversides, interconnect these hubs, enhancing the network's functionality (see Figure 1). They include conservation corridors, green belts, landscape linkages, and utilitarian corridors. Such linear GI elements, encompassing utility rights of way (e.g., water, power, gas, telephone lines) and river canals, are pivotal in connecting green space hubs, as elucidated by Wolstenholme (2003).

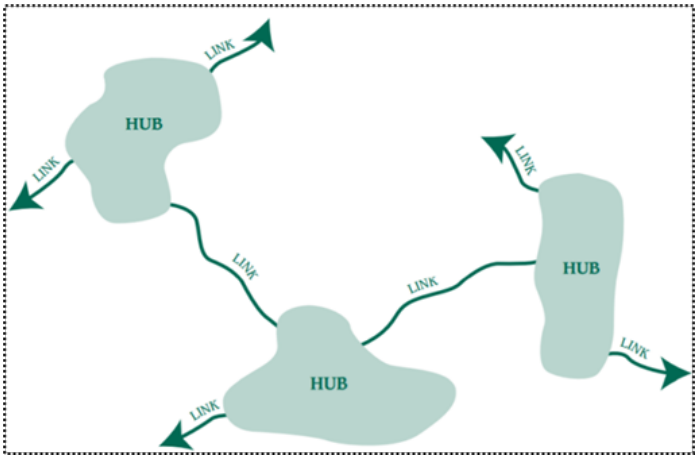



Figure 1 Conceptual Framework of Green Network (Wolstenholme, 2023)

## 2.2. Sustainable Green Infrastructure

The management and sustainable utilization of urban landscapes are intrinsically linked to the concept of "Ecological Resilience." This term refers to the capacity of ecosystems to absorb disturbances while changing yet retaining their core functional integrity. As Berghöfer et al. (2020) articulate, the essence of GI lies in its role as an environmental linchpin, utilizing significant control over socio-economic dynamics. Central to this understanding is the interplay between Natural Capital (NC) and Ecosystem Services (ES), which are fundamental in sustaining urban environments and maintaining the general balance of ecosystems Berghöfer et al. (2020). NC encompasses various environmental assets, including diverse species, communities, landscapes, ecosystems, soils, water, and air (see Figure 2). These elements collectively contribute to the wide array of services we derive from nature. Prominent among these services are carbon sequestration, erosion control, and water purification. In dense urban areas, outdoor GIs play a pivotal role in providing these varied ecosystem services, reinforcing the resilience and sustainability of urban landscapes.

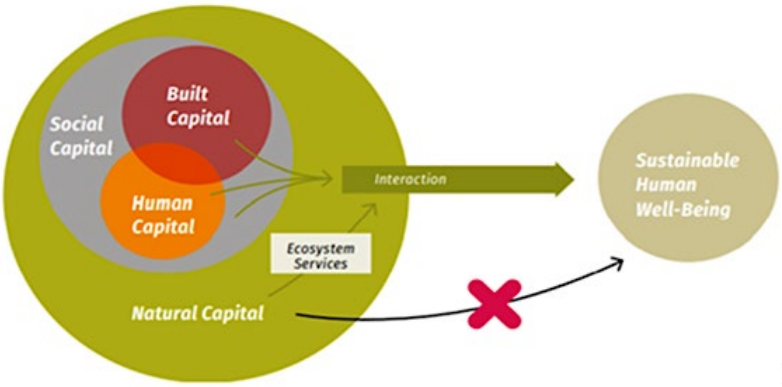



Figure 2 Natural Capital and Ecosystem Services (Berghöfer et al., 2020)

### 2.3. Heritage Spaces and Green Infrastructure

Built heritage spaces have robust functions as the centers of attraction for local and non-local visitors. Therefore, these spaces should be integrated with GI. According to Coombes & Viles (2021), integrated heritage can have many advantages, which include: (1) Health and well-being: heritage sites create a bridge between the past and present, enhancing visitor satisfaction and generating memorable experiences; (2) Environmental benefits: these spaces regulate urban temperature, balance $CO_2$ and $O_2$ levels, and improve air quality, furthermore, GI can mitigate climate variability and protect heritage buildings from environmental damage, including overheating effects and water or wind infiltration (McLean, 2017); (3) Biodiversity centers: heritage sites facilitate the free movement and integration of plant and animal species, fostering biodiversity and cultural richness; (4) Water quality improvement: green heritage sites are crucial in reducing runoff, managing waste, and enhancing groundwater infiltration, thereby improving water quality downstream; (5) Urban agriculture promotion: these spaces can be utilized for gardening activities, like growing vegetables and flowers, as knowledge-sharing centers for agricultural and cultural services; (6) Noise reduction: well-vegetated heritage sites act as buffer zones, reducing urban traffic noise; (7) Employment opportunities: the management, maintenance, and operation of heritage sites require significant human resources, thus creating job opportunities; and (8) Social interaction and cohesion: heritage sites are unique in attracting diverse groups of people facilitating social interactions and cohesion. Di Turo & Medeghini (2021) note that few services can rival heritage sites in promoting social relations. Therefore, it is crucial that urban planning and GI initiatives strategically incorporate heritage sites, ensuring they are interconnected and equipped with essential services such as vegetation and utilities, as advocated (Alfasi & Fabian, 2009).

### 2.4. Creating Interconnected Green Infrastructure

The enhancement of GI is crucial in urban planning and can be achieved through several strategic initiatives, which include:

1. Improving pedestrian accessibility and connectivity by expanding pedestrian pathways, such as walkways within parks and sidewalks, makes green spaces more accessible and connected. Firmansyah et al. (2018) emphasize the importance of such infrastructure in augmenting cities' overall attractiveness and functionality.
2. Enhancing accessibility to facilities by providing essential amenities like car parking, shelters, and clear directional signage is vital in increasing the use of green spaces. The accessibility of these services directly influences the frequency of park usage by nearby residents, leading to more active interaction with the environment.
3. Ensuring safety and security measures by addressing safety concerns through adequate lighting, robust infrastructure, clear signage, and security presence can significantly reduce crime and fear, making green areas more inviting.
4. Improving aesthetic enhancement by adding thoughtful design elements that enhance attractive views and restrict undesirable ones, along with creating vantage points, can significantly boost the aesthetic appeal of green spaces.
5. Increasing economic benefits and the 'Proximate Principle'. According to Crompton (2007), the proximity to parks and squares correlates with increased environmental, social, and economic values, a concept known as the 'proximate principle.' Property values are higher near well-maintained GI, underscoring its economic significance.

6. Advancing green transportation and crime reduction by encouraging green transportation modes like cycling and pedestrian access, coupled with sufficient lighting and crime prevention strategies, can increase the utilization and safety of these spaces. Bowman et al. (2009) highlights that individual who engage with their environment are generally healthier than those confined to purely constructed urban areas.

Therefore, the interconnectedness of GI, encompassing pedestrian and cycling routes, safety measures, and aesthetic improvements, is integral to enhancing urban livability. These measures increase the usability of green spaces and contribute to the overall health, safety, and economic prosperity of urban communities.

## 2.5. Qualities of Green Infrastructure

The effectiveness of GI is gauged by its ability to fulfill users' environmental, health, social, and economic needs. Sugiyama et al. (2009) note the significant usage of GI by older populations, particularly in closer proximity. The overall attractiveness of a city is notably enhanced by sustainable GIs, which can be observed in the vibrancy of neighborhood movements, cafes near main roads, and specialized parks. Stessens et al. (2020) suggest that the quality of GI is best measured by its fitness for intended purposes, including accessibility, inclusivity, maintenance, and functionality.

### 2.5.1. Environmental Sustainability by Green Infrastructure

GI is critical in modifying climate and micro-climate conditions, such as controlling sun radiation, reducing temperature, and minimizing wind speed. It also contributes to lower energy usage through natural shading and green roofs and walls. Hydrological regulation is another key aspect, achieved through bio-swales, permeable pavements, and retention ponds. Furthermore, GI facilitates waste decomposition and biodiversity enhancement, as outlined (Firmansyah et al., 2018; Lee & Kim, 2015; Trica et al., 2019).

The morphology pattern and properties of urban surfaces determine the micro-climate of an area. The street corridors, public places, and GIs regulate the change in climate in urban areas. Wind speed decreases in green GIs (Ogryzek et al., 2020). Interconnected GIs lower energy use, by covering buildings with green roofs and green walls and have shading by trees (Firmansyah et al., 2018). They have many cooling effects on walls, roofs, and surrounding backyards. The street side corridors and pedestrian footpaths will significantly reduce energy if they are well preserved, and the land is escaped. In cold and temperate zones, selected and evergreen plants are important. The use of the plantation may be to break and moderate wind and airflow in and out of the city (Pan et al., 2019).

The other important use of GI is fostering hydrological regulation (Firmansyah et al., 2018). The hydrological cycle begins with the sun's energy in the solar system of the universe, giving energy to the earth's surface. Trees and grass cover the earth's surface, and surface waters evaporate the lower-energy air back into the atmosphere. This pattern regulates the water cycle. “The denser plants in the area, the better flow of rainwater is created.” The other important aspect of GI is enabling water percolation and reducing soil erosion (World Meteorological Organization, 2008).

GIs enable waste decomposition and cycling. The degradable wastes are decomposed in GIs. These spaces cover different waste separation techniques according to material type and degrading capacity. They also reduce waste treatment plants. They have different recreation areas as well. The solid waste system, from waste production to sludge disposal into selected landfills, is regulated by natural processes.

### 2.5.2. Health Sustainability by Green Infrastructure

Interconnected GIs significantly improve mental well-being by reducing mental fatigue and promoting healthier emotions, as observed (Firmansyah et al., 2018). Mental well-being has two elements. It includes happiness, life satisfaction, self-realization, and psychological function (Houlden et al., 2017). GIs also reduce mental fatigue and stress (Beyer et al., 2014). Outdoor activities such as walking, sports, physical observing, swimming, playing with friends, and other activities change the mindset and bring health to mind (Lestan et al., 2014).

### 2.5.3. Social Sustainability by Green Infrastructure

GI improves social relationships (social interaction, integration, and cohesion) (Firmansyah et al., 2018). The degree of people integration or mix is higher as people meet regularly. People perceive the place they have spent more time with, likely famous friends, families, or relatives. They create social bondage or cohesion. Regular encounters in green spaces can lead to lasting friendships and a strong sense of community (Chen et al., 2016; Ridwan et al., 2017; Salih & Ismail, 2017). Physical spaces for various activities, including sports and leisure, are essential for nurturing social bonds and tourism. Outdoor activities such as design, multi-functionality, and creating access and user characteristic studies encourage tourism attraction (Salih & Ismail, 2017).

### 2.5.4. Economic Sustainability by Green Infrastructure

Sustainable spaces increase the economic status of the neighbors. These spaces encourage a rise in property values (land and property price) and increase local economic activity (attraction of local visitors, non-local visitors, and street vendors) (Firmansyah et al., 2018). These uses and differences from the other specific locations increase the demand for the location. This internship increases housing prices (Camargo, 2016). These GIs encourage outdoor activities along the street corridors and street cafes. They also attract retailers, businesspeople, and tourists to the site. Thus, landscape change and the quality enhancement of GIs attract people; they can be locals, people outside the neighborhood, and internationals (Camargo, 2016; Zhu et al., 2019).

### 2.5.5. Cultural Sustainability by Green Infrastructure

GIs encourage sociocultural sustainability. They improve urban farming (backyard gardening, green walls, green corridors) and create opportunities for recreation, tourism, and social interaction (the facilities are toilets, showers, animal play, fountain, colored plants, and landscaping) (Firmansyah et al., 2018). Urban farming creates the best role, from growing foods and fruits at the plot level to the neighborhood level, growing farmlands, and providing sufficient food for the community's urban spaces. The way urban expansion is used decreases the level of agricultural land. However, the increment of urban green GIs for different planting, fruiting, and growing crops enables the return of normal food security. Ridwan et al. (2017) state that edible landscape fruit planning and design promote food security.

## 2.6. Managing Green Infrastructure and User Experiences

Effective management of GI, pivotal in fostering social, economic, and environmental benefits, requires a multifaceted approach. Eagles et al. (2010) categorize management models into eight distinct types, each defined by its level of accountability and risk management. These models include: (1) National Park Model managed by the government, which focuses on providing and

maintaining park resources; (2) Parastatal Model that is provided by the government but operated with greater financial flexibility; (3) Non-Profit Organization Model that emphasizes conservation and advocacy, often in collaboration with public entities; (4) Public and For-Profit Combination Model, which is a partnership model between government and business organizations, leveraging public responsibility and private efficiency; (5) Public and Non-Profit Combination Model that combines public resources with non-profit organizations' advocacy and conservation focus; (6) Eco-Lodge Model that is tailored for eco-tourism, balancing environmental conservation with hospitality; (7) Aboriginal Combination Model: Integrates traditional and indigenous practices in natural resource management, predominantly in rural areas; (8) Traditional Community Model that relies on community-led initiatives and traditional methods of managing green spaces.

According to Eagles et al. (2010), the 'national park model' is where the government provides and manages park resources. The 'parastatal model' is provided by the government but with financial flexibility. The 'public and for-profit combination model' creates a partnership between government and business-making organizations, and in 'the public and non-profit combination model, the non-profit organization plays an advocacy role and focuses on natural resource conservation. Ecology and aboriginal models are used in rural areas for natural resource management.

Green space infrastructure needs continuous management. Managing the available resources, maintenance, financing, sanitation, and facilitating encourage the community. The multifunctional approach to sustaining ecological, economic, and social requires integrated management. The Ethiopian government has adopted a similar fashion. According to (Yirga Ayele et al., 2022), the familiar green spaces management approaches are (1) fully public, (2) public utility, (3) outsourcing, (4) private-no-profit and (5) private for-profit models.

## 2.7. Green Infrastructure's Design Principles

GI has several design principles that cover several aspects, including connectivity, multi-functionality, multi-scale, integration, diversity, applicability, and continuity (see Table 1).

Table 1 Green Infrastructure's Design Principles

| Principle | Description |
|---|---|
| Connectivity | Connectivity aims to create a well-connected green space network that can serve both humans (recreation) and other species, namely fauna and flora (migrations and interactions). |
| Multi-functionality | Multi-functionality connects GI with the provision of ecosystem services, regulation, support, and culture. |
| Multi-scale | Multi-scale refers to the different levels of the infrastructure plan. This enables the interactions between spaces. |
| Integration | Integration mainly concerns the interactions and links between GI and other urban structures (grey infrastructure) |
| Diversity | Diversity enhances the different existing structures (managed/artificial or natural), their size (small or large), and the nature of the areas (green or blue). |
| Applicability | Applicability refers to whether the GI is realistic, can be implemented and developed, and whether the solutions presented are adaptable to the area. |
| Continuity | Continuity refers to a monitoring system of GI throughout time, which can (or cannot) include periodic evaluation reports/communications. |

Source: Monteiro et al., 2022

## 3. METHODOLOGY

### 3.1. Research Design

This research employs a combined quantitative and qualitative approach to obtain its three objectives. The methodology encompasses several key steps:

1. Satellite image analysis: utilizing secondary data, a classification and land cover analysis of the area using Sentinel-2 satellite imagery we conducted. This step allowed for a broad, objective assessment of the current state of GI.
2. Observational study: complementing the satellite data, primary data were gathered through direct observation. This method provided insights into green spaces' physical conditions and usage patterns.
3. Public perception survey: a questionnaire-based survey was conducted to gauge community engagement and needs. This survey aimed to understand the public's perspectives on accessibility and the availability of facilities within the green spaces, such as toilets and play fields.

The goal of this research design was to accurately assess the level and quality of GI in the study area. By integrating insights from Sentinel-2 images with observational data and public feedback, this study aimed to construct a comprehensive understanding of the green spaces, including their utilization and the needs they fulfil for the community. Figure 3 shows the design of the reseach methods.

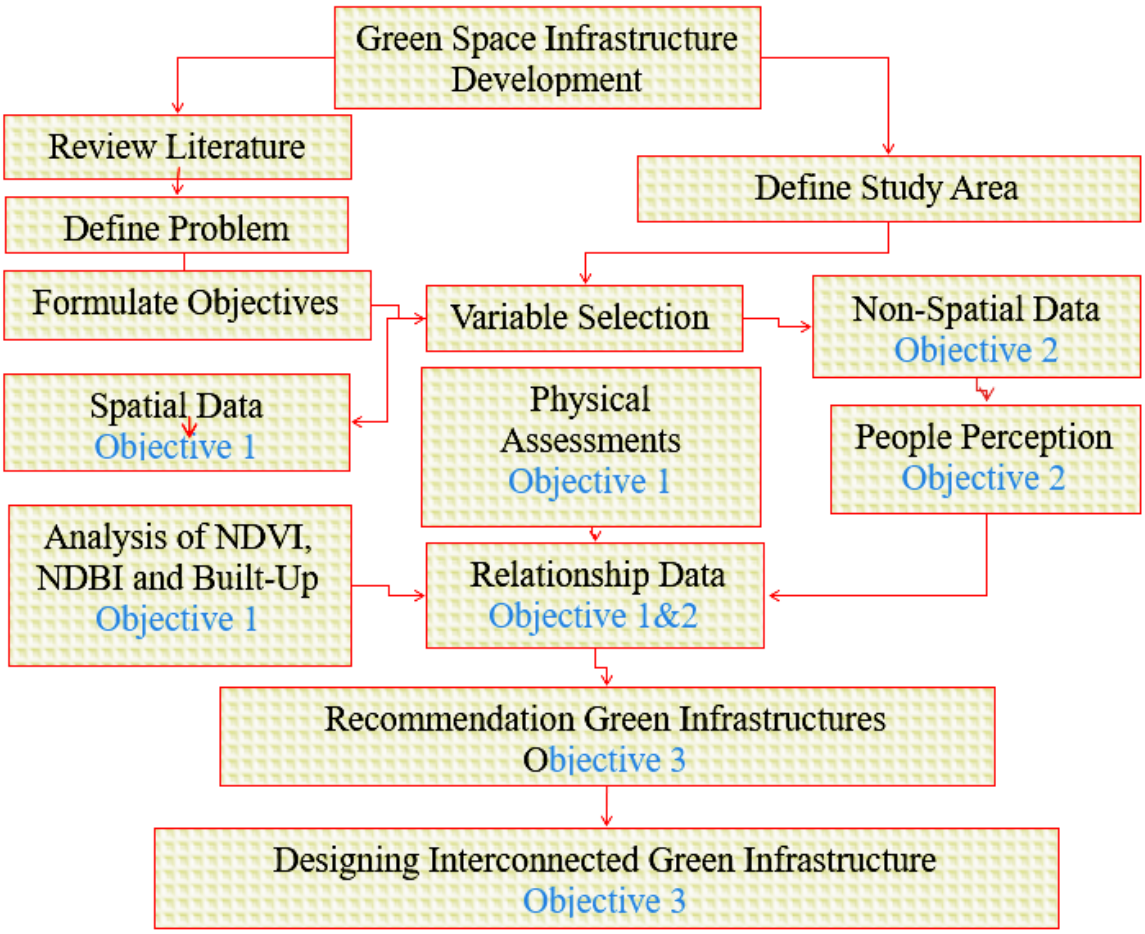



Figure 1 Methodological Design

### 3.2. Quality of Green Infrastructure

To evaluate the quality of GI in the study area, a dual-method approach outlined in the methodological design were implemented. This approach combines quantitative satellite image analysis with qualitative field observations (see Figure 4).

1. Quantitative Analysis:
   a. Satellite Image Analysis, which utilizes Sentinel-2 satellite imagery to analyze the area's land use patterns. Key indicators used in this analysis were the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI). The NDVI is instrumental in assessing the presence and quality of vegetation, while the NDBI is used to evaluate built-up areas.
   b. Index Comparison and Interpretation, which compares NDBI and NDVI values to determine the adequacy level of GI. The Built-Up (BU) area is quantified as the difference between NDBI and NDVI values. These calculations used Geographic Information System (GIS) and Quantum Geographic Information System (QGIS) tools.
   c. Storm Water Management Systems (SWMS) are analyzed, and their effectiveness are evaluated based on NDVI, NDBI, and BU indices. This analysis helps justify low-impact SWMS's impact on the quality of GI.
2. Qualitative Analysis includes conducting field observations focused on assessing the distribution of vegetation, water availability, catchment areas, and the functionality of various stormwater management systems, such as bio-swales, retention ponds, cisterns, and permeable pavements.

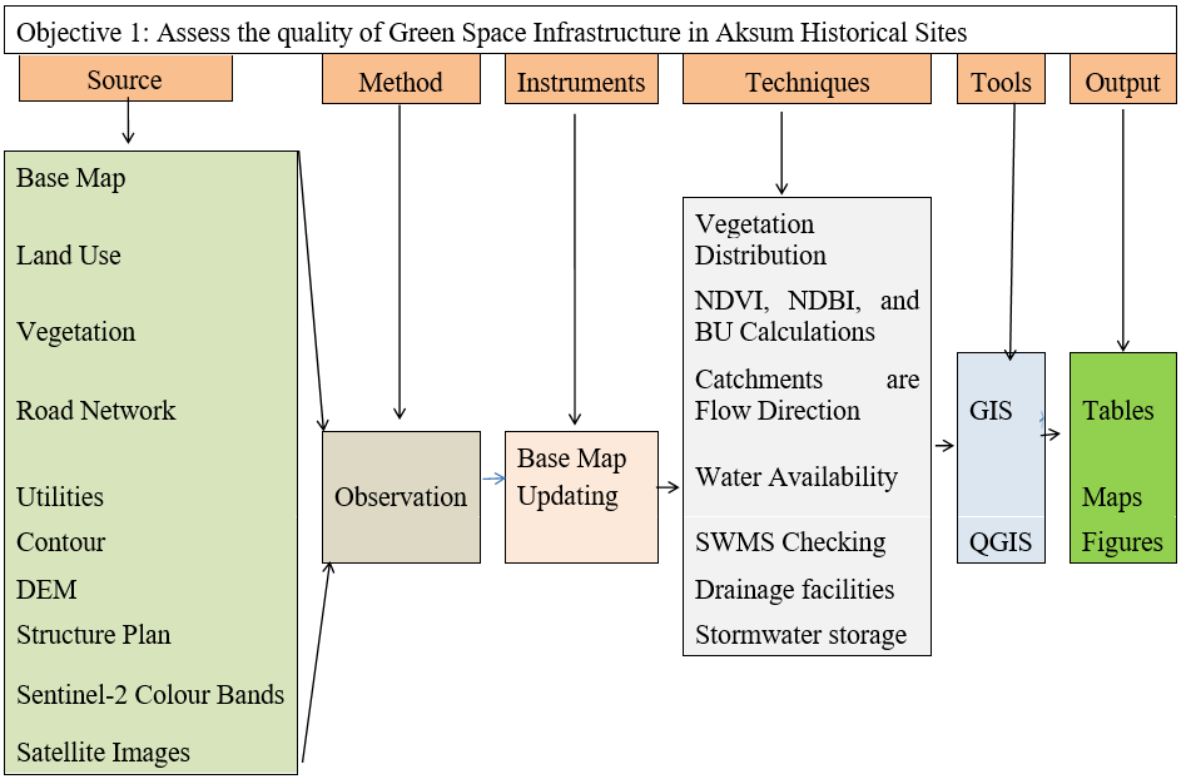



Figure 4 Input Output Diagram for GI Quality Evaluation

The 'Urban Built-up' Index helps understand the level of green space infrastructure, calculated using formula (1):

$$BU = NDBI - NDVI \quad (1)$$

The distribution of vegetation, water availability, catchment areas, and stormwater management systems like bio-swale, retention ponds, cisterns, permeable pavements, and further drainage facilities are studied by field observation.

According, Lange et al. (2017). NDVI is calculated from Sentinel 2 images using this formula:

$$NDVI = \frac{NIR(B8) - RED(B4)}{NIR(b8) + RED(B4)} \quad (2)$$

The NDVI result is measured -1 up to -0.02 = water body, -0.02 up to 0.1 = Rocky area, 0.1 up to 0.5 = Grass and Shrubs, and 0.5 up to +1= dense vegetation.

NDBI is calculated by the formula by color bands indicated in Table 3 (Kuc & Chormański, 2019) above, and it is obtained using this formula:

$$NDBI = \frac{SWIR\ (B11) - NIR\ (B8)}{SWIR\ (B11) + NIR\ (B8)} \quad (3)$$

NDBI result is measured by the image result in which -1 up to zero (0) = water body and zero (0) up to +1 is Built-up Area.

### 3.3. User Perceptions in Green Infrastructure

3.3.1. Population and Sample Size

The people's perceptions of visitors' sample size were determined by given by:

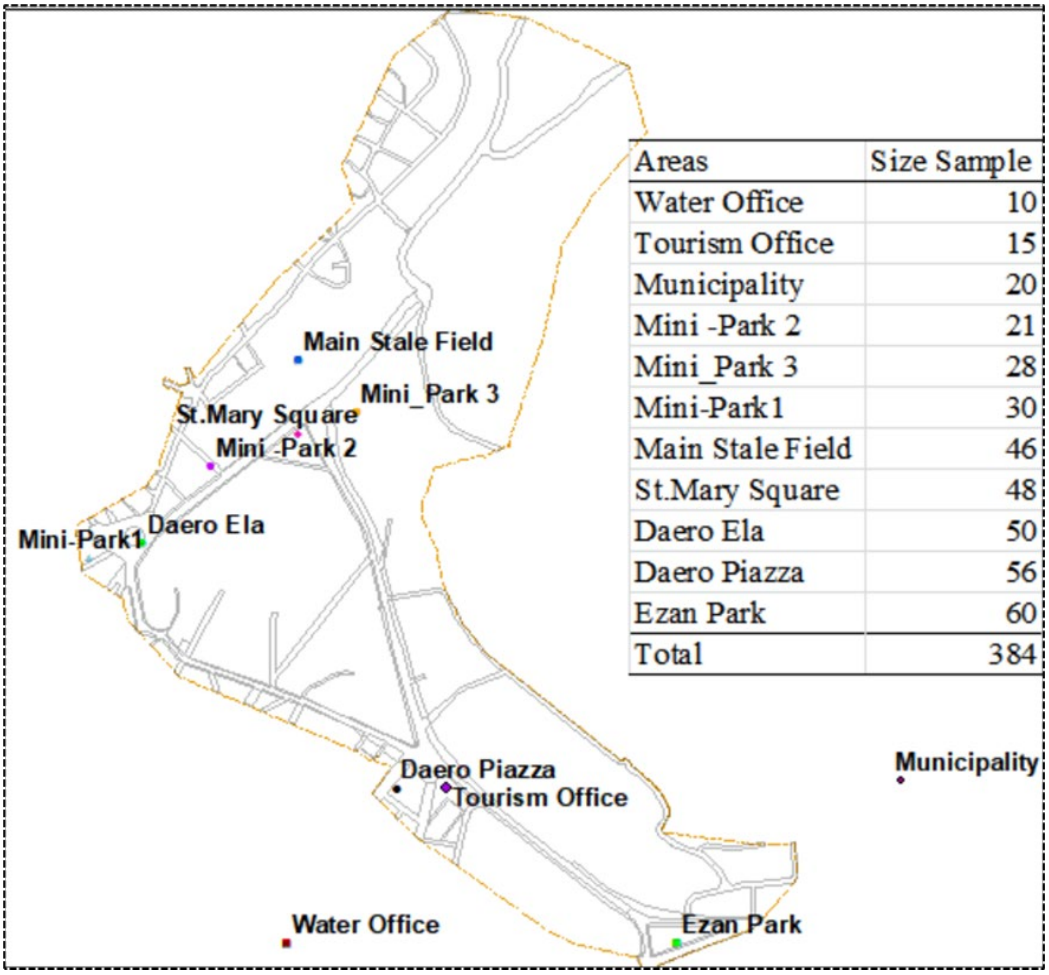
$$n = \frac{z2pq}{d2} \quad (4)$$

where $n$ is the desired sample size, $z$ is the standard normal deviation usually set at 1.96 (which corresponds to the 95% confidence level), and $p$ is the proportion in the target population to have a specific characteristic if no estimate is available set it at 50% (or 0.50), $q = 1 - p$ and $d$: absolute precision or accuracy normally set at 0.05.

$$n = \frac{(1.96)2(0.5)(0.5)}{(0.05)2} \text{ hence, } n = 384 \text{ has taken.} \quad (5)$$

The survey method employed was a typical purposive sampling technique. Under each category, the samples were selected if they can independently read and write to answer questions. The selection of these stakeholders, such as a municipality, tourism office, and water office were based on their requirements. The availability of visitors in the GI spaces enabled us to distribute the size from the lowest to the highest, as is seen in Figure 5.

The survey method employed was a typical purposive sampling technique. Under each category, the samples are selected if they can read and write to answer independently. The selection of these stakeholders, such as a municipality, tourism office, and water office, was based on their requirements.




| Areas | Size Sample |
|---|---|
| Water Office | 10 |
| Tourism Office | 15 |
| Municipality | 20 |
| Mini -Park 2 | 21 |
| Mini_Park 3 | 28 |
| Mini-Park1 | 30 |
| Main Stale Field | 46 |
| St.Mary Square | 48 |
| Daero Ela | 50 |
| Daero Piazza | 56 |
| Ezan Park | 60 |
| Total | 384 |

Figure 5 Sample Size in Each GI Space

### 3.3.2. Data Collection Instruments and Methods

After allocating the number of respondents to be asked from each GI space and office, questions of single and multiple responses were prepared to assess the user perceptions regarding GI in the study area. The questions were single response (Q1-Q5), multiple response Q6 (1-10), Q7 (1-6), Q8 (1-6). The multiple response variables were grouped and defined into one variable set in the analysis using the Statistical Package for Social Science (SPSS) software. The input and output for the second objective is shown in Figure 6.

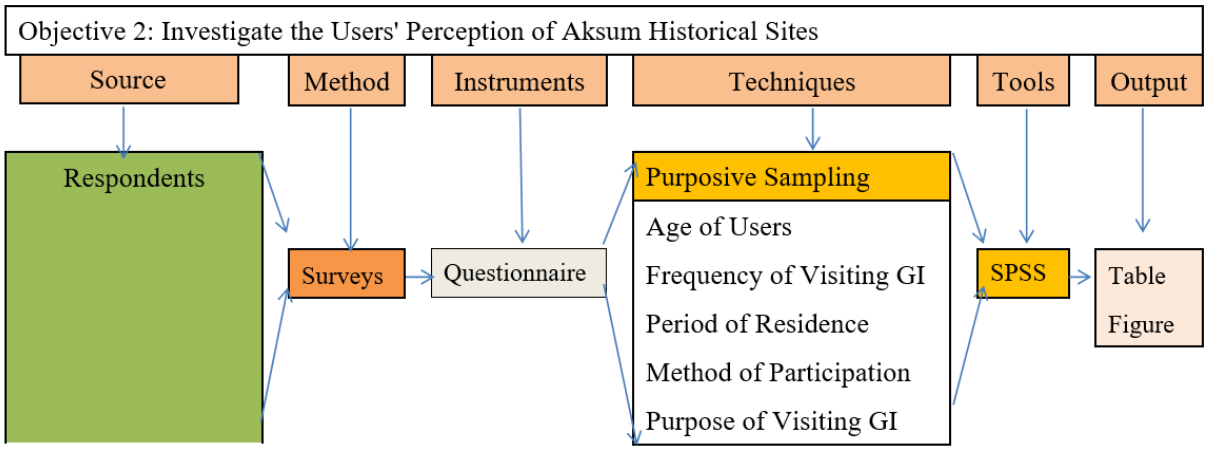



Figure 6 Input Output Diagram for User Perception

The responses to questions in Table 2 were collected and analyzed using the SPSS tool. The multi-response questions are coded for easier work, and the result is cross-tabulated.

Table 2 People Perception Questionnaire

| No | Question | Code | Variable |
|---|---|---|---|
| 1 | Gender | 11 | |
| 2 | Age | 21 | |
| 3 | Period of Residence | 31 | Period of residence in the town |
| 4 | Frequency of Visiting | 41 | Frequency of visiting Green Space |
| 5 | | 51 | Regular Maintenance of Green Space |
| 6 | Main Purpose of Visit | 61 | Relaxation |
| | | 64 | Relate Nature |
| | | 65 | No other Places |
| | | 66 | Attending Community Events |
| | | 67 | Spend Time |
| | | 68 | Family Recreation |
| | | 69 | Social Contact |
| | | 610 | Education For Children |

| No | Question | Code | Variable |
|---|---|---|---|
| 7 | Types of Parks to Visit | 71 | Pocket parks around homes |
| | | 72 | Children Parks |
| | | 73 | Riverside stream park |
| | | 74 | Performance and cultural parks |
| 8 | Methods of participation | 75 | Sport Park |
| | | 76 | Mountain Parks |
| | | 81 | I am not particularly eager to change |
| | | 82 | Joining with the non-profit organization |
| | | 83 | Participating in volunteer workers and clean environment |
| | | 84 | Enforcing politicians to have a guide for GI |
| | | 85 | Agreement to pay tax for using the service |

### 3.4. Integration of Green Infrastructure

Observation and image processing findings have analyzed the connectivity, integration diversity, and multi-functionality of GIs. The assessment data included the total origin and destination sites and necessary links and hubs. The completeness of the network or missing part was analyzed, and the result was drawn in two-dimensional Drawings (2D). The input and output for the third objective is shown in Figure 7.

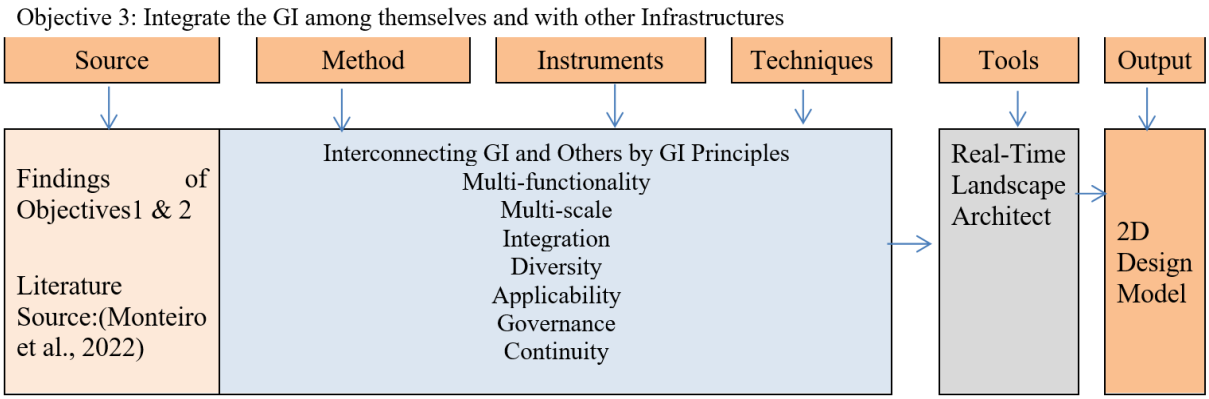



Figure 7 Input Output Diagram for GI Integration

# 4. RESULT AND DISCUSSION

## 4.1. Qualities of Green Infrastructure

### 4.1.1. Calculation Normalized Difference Vegetation Index (NDVI)

The NDVI is the measure of the vegetation quality. This can measure the health of the vegetation and its distribution in the urban area. The raster calculation in this research was done by downloading Sentinel 2 images from Copernicus data source and NASA. The available color bands calculate the NDVI. The first step is clearing clouds and shadows on the surface of the analysis. Clouds and shadows can affect the NDVI result. Different brand names and imagery sources, such as Land Sat 7, 8, and Sentinel-2 level A, are known. This analysis research has used Sentinel 2 imagery from 'Copernicus' data source. Sentinel 2 has 13 bands of different color bands and wavelengths. The description is in Table 3.

Table 3 Sentinel 2 Color Bands and Resolution Available

| Band | Description | Wavelength(µm) | Resolution |
|---|---|---|---|
| B01 | Coastal aerosol | 0.433-0.453 | 60 |
| B02 | Blue | 0.458-0.523 | 10 |
| B03 | Green | 0.543-0.578 | 10 |
| B04 | Red | 0.650-0.680 | 10 |
| B05 | Vegetation Red Edge 1 | 0.698-0.713 | 20 |
| B06 | Vegetation Red Edge 2 | 0.733-0.748 | 20 |
| B07 | Vegetation Red Edge 3 | 0.773-0.793 | 20 |
| B08 | NIR | 0.785-0.900 | 10 |
| 8A | Narrow NIR | 0.855-0.875 | 20 |
| B09 | Water Vapour | 0.935-0.955 | 60 |
| B10 | SWIR - Cirrus | 1.365-1.385 | 60 |
| B11 | SWIR-1 | 1.565-1.655 | 60 |
| B12 | SWIR-2 | 2.100-2.280 | 20 |

Source: Devara & Wijayanto, 2021

Knowing the above specification for color bands, water surface and vegetation surface can be synthesized from downloaded imageries of separate bands from one up to 12 bands, as well as false color and true color bands. In Quantum GIS, the downloaded raster data was calculated according to the formula for NDVI. The result is interpreted where the normalized difference is given in data distribution in inclusive (-1, 1). Where -1 is a water body, and +1 is highly and densely vegetated (see Figure 8).

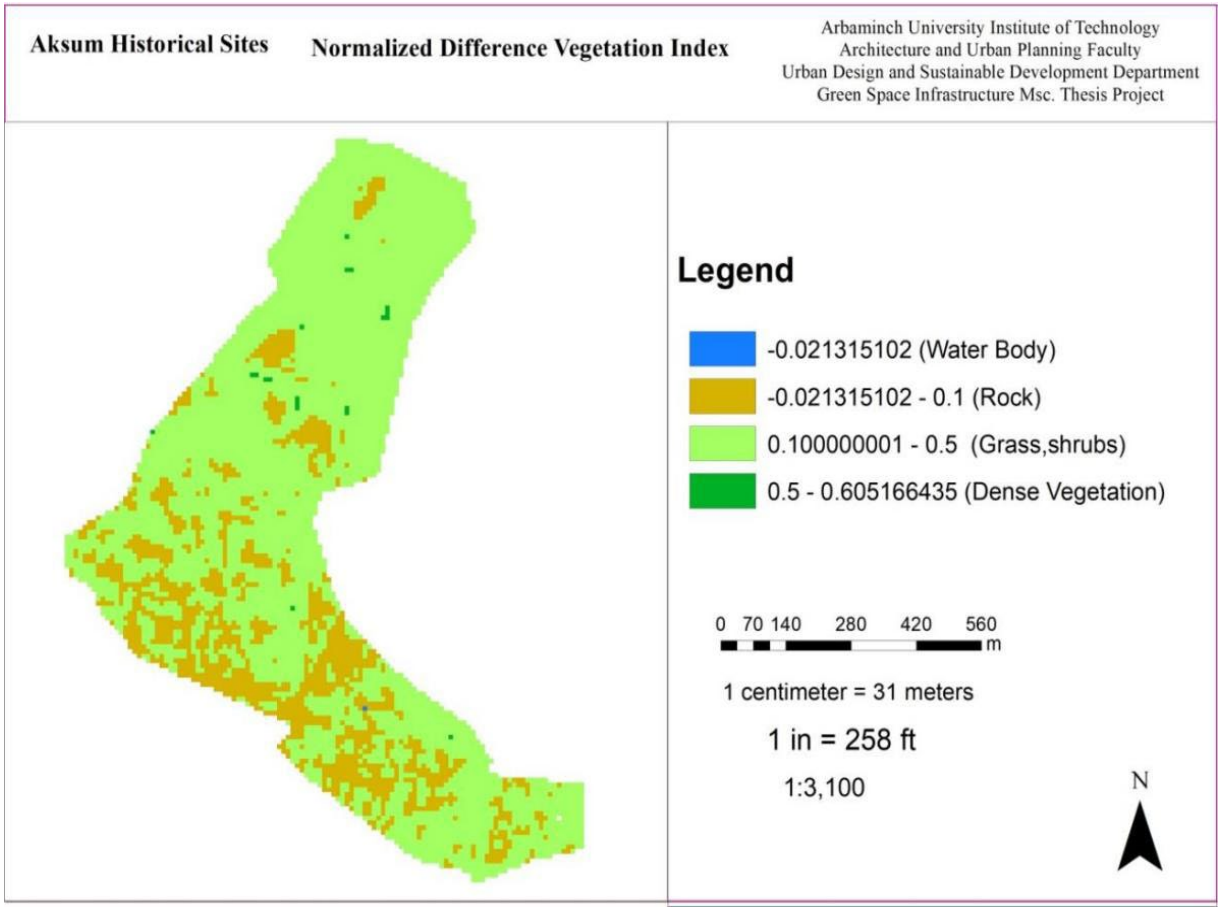



Figure 8 NDVI Result

NDVI is the index showing the probability of finding healthy vegetation, which ranges from -1 up to +1 inclusive. The crude analysis of NDVI from 'Sentinel 2' imagery indicates that map 4.34 is grouped into four. -1 up to -0.02 is considered a water body. The group from -0.02 up to +0.1 is considered a rocky area. Grasses and shrubs cover the result from +0.1 up to +0.5. The last healthy vegetation and grown-up trees are indicated by NDVI +0.5 up to +1 (see Table 4).

Table 4 NDVI Result

| Range | | Area ($M^2$) | Inference |
|---|---|---|---|
| -1 | -0.02 | 60.26 | Water Body |
| -0.02 | 0.1 | 142959.16 | Rock |
| 0.1 | 0.5 | 500270.58 | Grass/Shrubs |
| 0.5 | 1 | 1321.94 | Dense Vegetation |
| Total | | 644611.94 | |

The NDVI result shows a small area (0.132 Ha) of dense vegetation. The grass coverage was 50.02 Ha. The rest is scattered. The result found 14.29 Ha is rocky surface. The Zonal Statistics from GIS also showed that the proportions of different land use classes had different levels of Green Coverage (see Table 5).

Table 5 NDVI versus Land Use

| Land Use | Area (M2) | Min (NDVI) | Max (NDVI) | Range | Mean | Std. |
|---|---|---|---|---|---|---|
| Heritage Site | 52504.768 | 0.034 | 0.534 | 0.500 | 0.193 | 0.110 |
| Forest and Informal green | 38672.867 | 0.021 | 0.501 | 0.480 | 0.170 | 0.079 |
| Recreation | 14678.752 | 0.003 | 0.474 | 0.470 | 0.172 | 0.115 |
| Service | 109243.792 | -0.021 | 0.543 | 0.565 | 0.154 | 0.080 |
| Manufacturing and Storage | 188.189 | 0.105 | 0.204 | 0.100 | 0.154 | 0.050 |
| Administration | 18066.157 | 0.032 | 0.376 | 0.344 | 0.136 | 0.075 |
| Vacant Land | 88919.365 | 0.028 | 0.605 | 0.577 | 0.204 | 0.087 |
| River | 16278.360 | 0.063 | 0.505 | 0.442 | 0.251 | 0.090 |
| Residence | 103033.550 | 0.017 | 0.515 | 0.499 | 0.164 | 0.084 |
| Agriculture | 1693.702 | 0.108 | 0.243 | 0.134 | 0.160 | 0.042 |
| Mixed Use | 18160.251 | 0.033 | 0.456 | 0.423 | 0.150 | 0.084 |
| Commerce and Trade | 35755.935 | 0.056 | 0.565 | 0.509 | 0.198 | 0.083 |
| Road, Transportation, Utilities, and Infrastructure | 106138.671 | 0.010 | 0.524 | 0.515 | 0.164 | 0.089 |
| Sum | 603334.361 | | | | | |

The ‘Zonal Statistics’ regarding land use and respective NDVI index is illustrated in Table 5. The highest index is in vacant land, 0.028-0.605. It means that there is the highest vegetation indicator. However, the type of vegetation is shrubs and grass. The vegetation is intermittent and is not healthy. They can dry during the dry season. The second highest NDVI is recorded in heritage sites with a range of 0.034-0.534. The third highest NDVI is river stream and river buffer sides, which range from 0.063-0.501.

### 4.1.2. Calculation for NDBI

Normalized Difference Built-up index (NDBI) shows the areas with high reflectance and shorter wavelength infra-red spectral range (NIR). Quantum GIS calculates the sentinel-2 imagery of the given bands' raster images. The result of the image calculated is shown in Figure 9.

The NDBI is used to identify built surface and water bodies. The sentinel-2 imagery analysis and zonal statistics of different existing land use concerning the NDBI show that the range between -1 up to zero (0) is water body. The range between zero (0) and +1 is considered a built surface. The general analysis from map 4.35 indicates most of the area is built-up surface. The stream and its buffer labelled as water surface low range approaches -1. The zonal statistics of NDBI are also calculated. Land cover classes have different levels of built-up (see Table 6).

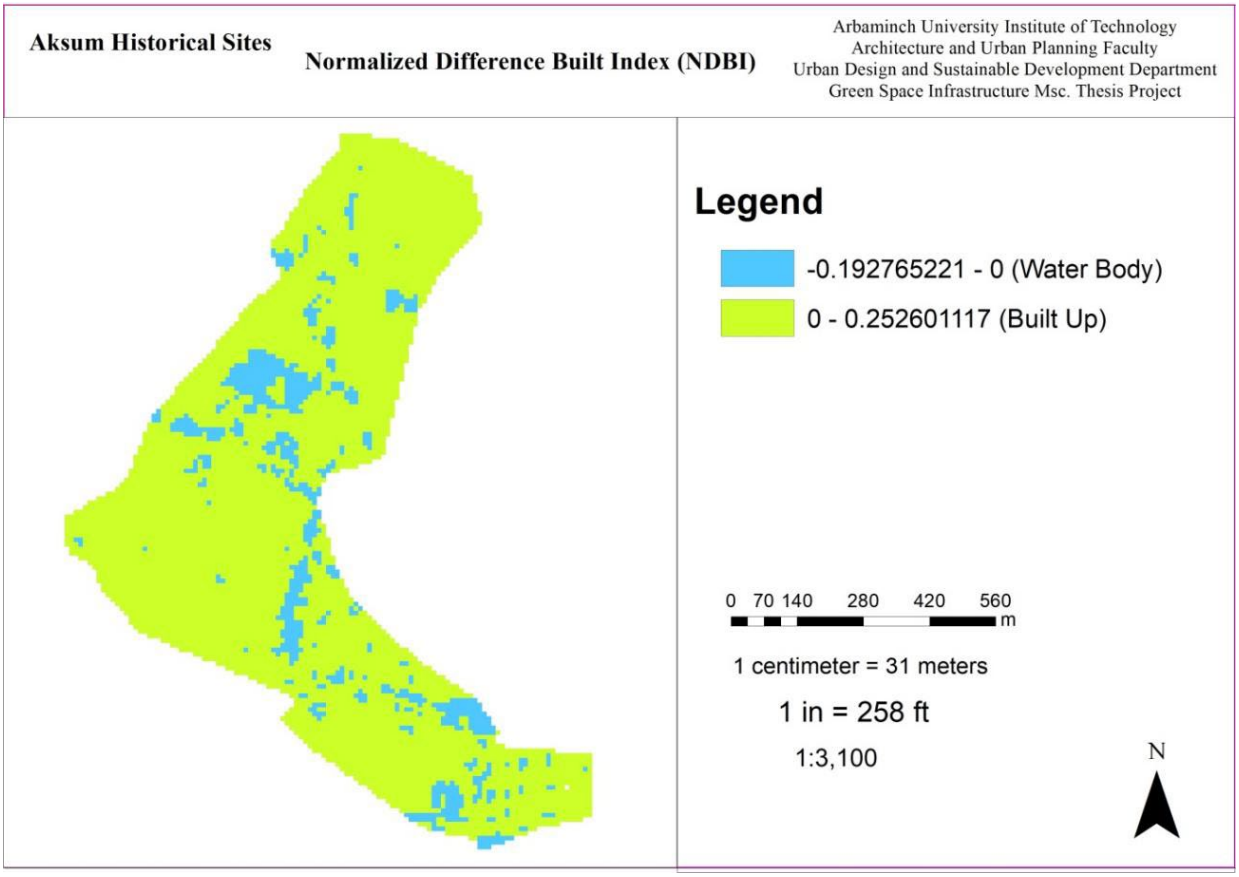



Figure 9 NDBI Analysis

Table 6 depicts that the NDBI result is lower at land use manufacturing and storage -0.004 up to 0.019 and higher at land use vacant land -0.193 up to 0.253. The NDBI cannot be the representative solution to show a built-up surface.

Table 6 NDBI versus Land Use Analysis

| Land Use | Area ($M^2$) | Min (NDBI) | Max (NDBI) | Range | Mean | Std |
|---|---|---|---|---|---|---|
| Heritage Site | 52504.768 | -0.136 | 0.144 | 0.280 | 0.036 | 0.051 |
| Forest and Informal green | 38672.867 | -0.110 | 0.239 | 0.349 | 0.083 | 0.068 |
| Recreation | 14678.752 | -0.145 | 0.131 | 0.276 | 0.027 | 0.059 |
| Service | 109243.792 | -0.108 | 0.203 | 0.312 | 0.055 | 0.045 |
| Manufacturing and Storage | 188.189 | 0.004 | 0.019 | 0.015 | 0.011 | 0.008 |
| Administration | 18066.157 | -0.105 | 0.132 | 0.236 | 0.042 | 0.042 |
| Vacant Land | 88919.365 | -0.193 | 0.253 | 0.445 | 0.086 | 0.063 |
| River | 16278.360 | -0.102 | 0.144 | 0.246 | 0.049 | 0.046 |
| Residence | 103033.550 | -0.128 | 0.240 | 0.368 | 0.056 | 0.047 |
| Agriculture | 1693.702 | 0.036 | 0.112 | 0.075 | 0.074 | 0.021 |
| Mixed Use | 18160.251 | -0.128 | 0.142 | 0.271 | 0.054 | 0.050 |
| Commerce and Trade | 35755.935 | -0.162 | 0.223 | 0.385 | 0.077 | 0.078 |
| Road, Transportation, Utilities, and Infrastructure | 106138.671 | -0.154 | 0.248 | 0.402 | 0.055 | 0.049 |
| Sum | 603334.361 | | | | | |

4.1.3. Calculation BU Index

Having calculated $NDVI$ and $NDBI$ indexes, the result raster image is also calculated in the raster calculator by $BU = NDBI - NDVI$ (Devara & Wijayanto, 2021), as illustrated in Figure 10.

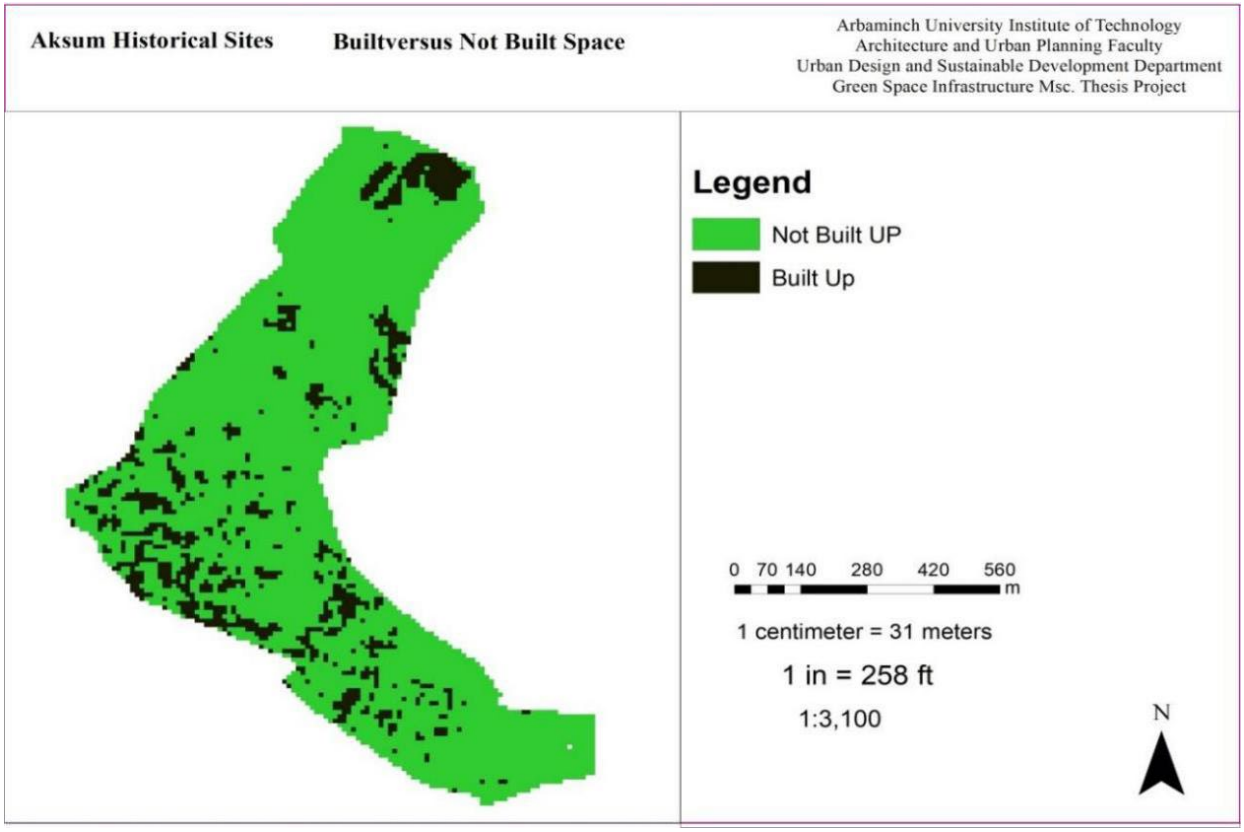



Figure 10 BU Index

The result of the probability of finding a built surface from the analysis is grouped into -1 up to +1. The below 0 or -1 up to 0 is not built surface, and from 0 up to +1 is built surface. The analysis is, therefore, grouped as indicated in the map in a dark color -0.033-+0.18 is the built surface. This comparison with the reality of surface cover seems true (see Table 7).

Table 7 BU Index Result

| Symbol | Range | | Area ($M^2$) | Inference | BAR |
|---|---|---|---|---|---|
| | -1 | 0 | 557022.49 | Not Built | |
| | 0 | 1 | 87766.26 | Built-Up | 0.13612 |
| Total | | | 644788.75 | | |

The total BAR (Built-Up to Total Ratio) indicates 0.136, 13.6 present built. However, the design for the green network is less. The comparative Built Up index with land use indicated by the structure plan is analyzed in different zones. The land use space with the highest built surface is residential area ranging from -0.644-0.128, and road and transport are built surfaces whose index ranges from -0.656- 0.109. In some cases, the forest and formal green indicated by the structure plan are violated and built with an index range of -0.57 up to 0.18. This generally depicts that the built surface and land use built, and non-built regulation is not respected (see Table 8).

Table 8 BU Index versus Land Use

| Land Use | Area ($M^2$) | Min (BU) | Max (BU) | Range | Mean | Std |
|---|---|---|---|---|---|---|
| Heritage Site | 52504.768 | -0.622 | 0.085 | 0.706 | -0.156 | 0.149 |
| Forest and Informal green | 38672.867 | -0.570 | 0.180 | 0.750 | -0.087 | 0.119 |
| Recreation | 14678.752 | -0.597 | 0.092 | 0.689 | -0.145 | 0.166 |
| Service | 109243.792 | -0.634 | 0.099 | 0.733 | -0.099 | 0.112 |
| Manufacturing and Storage | 188.189 | -0.185 | -0.101 | 0.084 | -0.143 | 0.042 |
| Administration | 18066.157 | -0.423 | 0.077 | 0.499 | -0.094 | 0.107 |
| Vacant Land | 88919.365 | -0.798 | 0.079 | 0.877 | -0.118 | 0.123 |
| River | 16278.360 | -0.607 | 0.042 | 0.649 | -0.202 | 0.124 |
| Residence | 103033.550 | -0.644 | 0.128 | 0.772 | -0.107 | 0.118 |
| Agriculture | 1693.702 | -0.204 | -0.035 | 0.169 | -0.086 | 0.048 |
| Mixed Use | 18160.251 | -0.584 | 0.080 | 0.664 | -0.096 | 0.125 |
| Commerce and Trade | 35755.935 | -0.724 | 0.054 | 0.778 | -0.121 | 0.136 |
| Road, Transportation, Utilities, and Infrastructure | 106138.671 | -0.656 | 0.109 | 0.765 | -0.109 | 0.122 |
| Sum | 603334.361 | | | | | |

### 4.1.4. Built-up versus Non-Built-Up

The built-up from Sentinel 2 images downloaded at different band resolutions and analysis results do not have built surfaces' accuracy. The roads and footpaths in the public institutions are not included. The built-to-total ratio is 0.14. The built-up to total (BAR) is 0.30. We found the vacant areas and mountain corridors that have indications of GI. There is no clear interconnection among the spaces. The result illustrated in Figure 11 shows the fragmented spaces' sites, hubs, and links, which are not interconnected. The GI result does not show a full network and meaningful web. The points of attraction (origin-destination) sites and hubs are not interconnected by the linear spaces like riverside buffer green, utilitarian corridors like verges and street side; Storm Water Management (SWM) systems like bio-swale, rain gardens, and permeable pavements are not connected by links with sufficient circulation as footpath and road network. Generally, the link is missed even though the sites have some implications for GI.

Figure 11 Fragmented GI Spaces

## 4.2. Sensory Perception for Green Infrastructure Development

### 4.2.1. Gender versus Frequency of Visiting Green Infrastructure

More time can be spent in green spaces if sufficient services are incorporated. The movement characteristic of the people and availability of jobs and recreation in proximities determines this. The more green spaces were integrated with working areas, homes, and industries, GI's most frequently visited spaces (see Figure 12). The gender relation with frequency illustrates that mostly female visitors occupy the spaces in Aksum recreational parks (Ezana, Daero Ela, and Daero Piazza). This can be done to create business in open recreation. The nature of the observed green spaces is that they are open for all private workers (females) and serve coffee, tea, and other soft drinks for visitors.

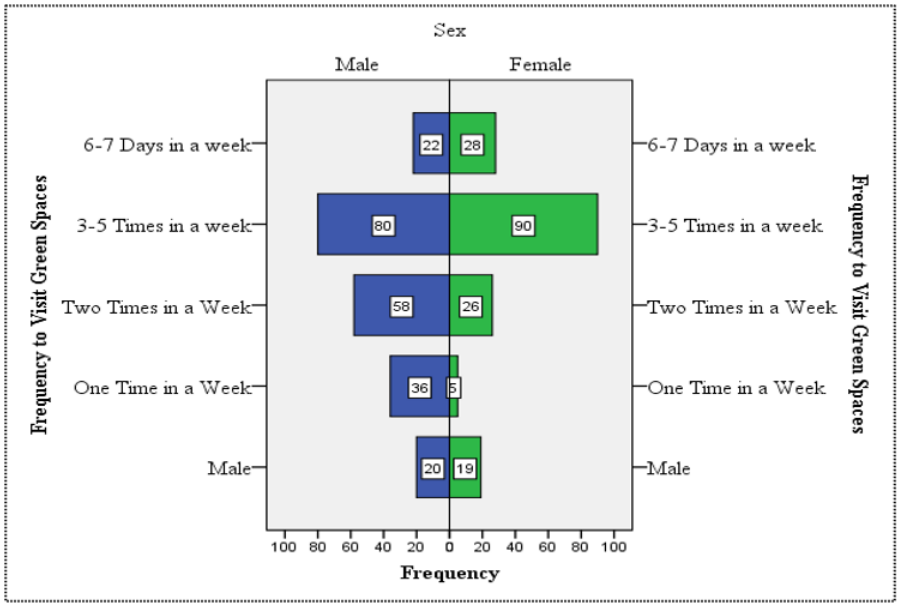



Figure 122 Frequency of Visiting GI

4.2.2. Gender versus Period of Residence and Maintenance GI

Many responses showed that no maintenance has been made to GI. The single-response questionnaire had 384 respondents. Therefore, the summation in each category is divided by 384 and multiplied by 100 to get a percentage. For example, the age groups over ten years have 198 out of 384, and the percentage is 51.6% (highest). The GI spaces are characterized by less maintenance. The respondents with more than ten years of residence have admitted that they have an almost similar understanding of the maintenance of GI. However, green space infrastructures need regular maintenance by the government, non-governmental organizations, or contractors.

4.2.3. Methods of Participation Development of GI

Table 9 Participation in GI Maintenance

| Variables | Responses | | Percent of Cases |
|---|---|---|---|
| | N | Percent | |
| I do not want to Participate | 73 | 5.4% | 19.0% |
| Joining with Non-profit Organizations | 158 | 11.7% | 41.1% |
| Agreement with Paying More Tax on Usage Services | 225 | 16.7% | 58.6% |
| Participating by Ideas/Knowledge | 250 | 18.6% | 65.1% |
| Volunteer Work in the Cleaning Environment | 297 | 22.0% | 77.3% |
| Donation of Business and Labour Participation | 344 | 25.5% | 89.6% |
| | **1347** | **100.0%** | **350.8%** |

The respondents participated in GI maintenance by labor in cleaning roads and environmental sanitation (77.3%). Participating in business or labor covers 89.6 %. Ideas and knowledge sharing also cover d 65.1%. Generally, 1347 multi-response cases have been collected, and the participation method has been ordered in ascending order in the table above. The people participate during the initiation to work and clean the environment, as Table 9 illustrates. According to the result, people have participated in keeping, watering, cleaning, and knowledge sharing.

### 4.2.4. Gender versus Main Purpose of Visiting GI

Different motives for GI visiting have been set. The multi-response variables are summarized in the graph. The chart showed that meeting with friends had the highest share, 315 out of 1664. The percentile was 20.5%. The next was for 'Relaxation', which accounts for 18.93%. The chart, therefore, illustrated the frequencies of answers. One can sum up the gender count in each response, divide it by 1664, and multiply it by 100 to find the percentage. Generally, this is good descriptive that by the multi-response question, in this case, people of different age groups, genders, and income levels visited green spaces for different cases (see Figure 13).

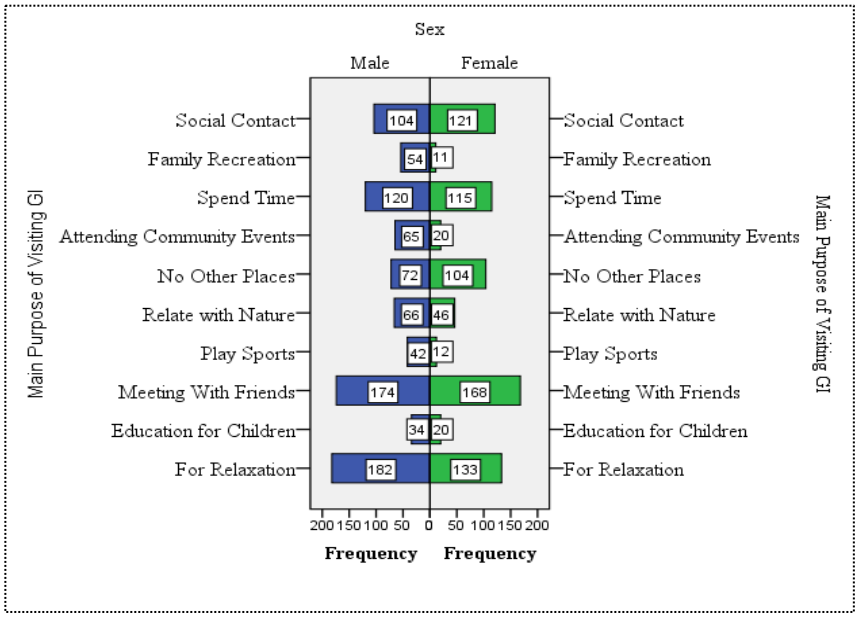



Figure 13 Gender versus Main Purpose of Visiting GI

### 4.2.5. Gender versus Types of Parks Visited

Figure 14 showed that pocket parks have the highest share of visitors. 256 out of 787 cases confirmed this. The next highest was found in sports parks, accounting for 51.2%. Sports performance and cultural parks were the next highest (in the case of Daero Ela and Daero Piazza).

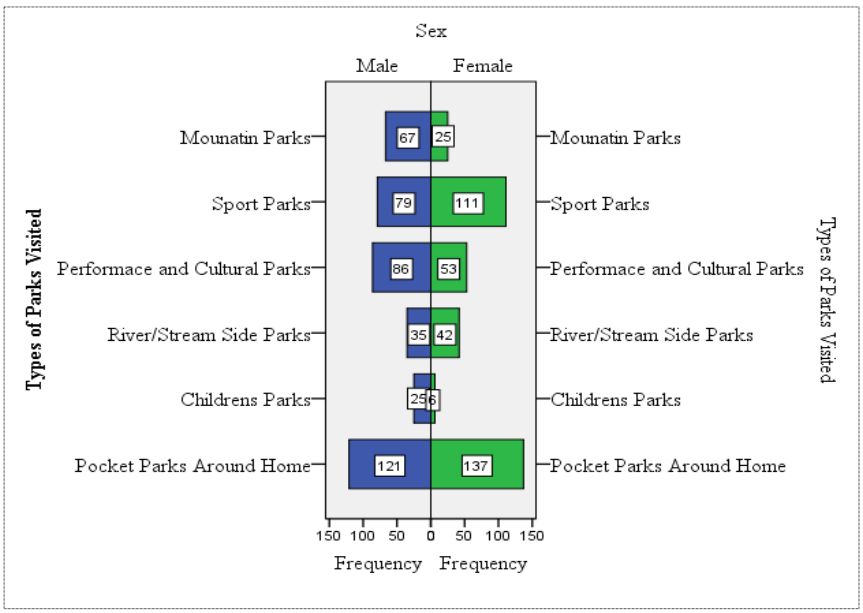



Figure 14 Types of Parks Visited

### 4.3. Integrating Green Infrastructure Spaces

The GI development has been applied inside the neighborhood river/stream corridors, street channels, roundabouts, median and overpass bridges, vacant spaces, existing parks, historically preserved areas, civic squares, and street leftover spaces. The spaces have to be connected by green. Users will have different options for using spaces in the outdoor environment, and pedestrians, tourists, local visitors, and residents in general will be comfortable if the green network concept is applied. The green concept integrated all the spaces of public and private frontages. The GI spaces are integrated using links like river corridors, linear landscapes, street-side greens, and road verges. The missed design is elaborated on in Figure 15.

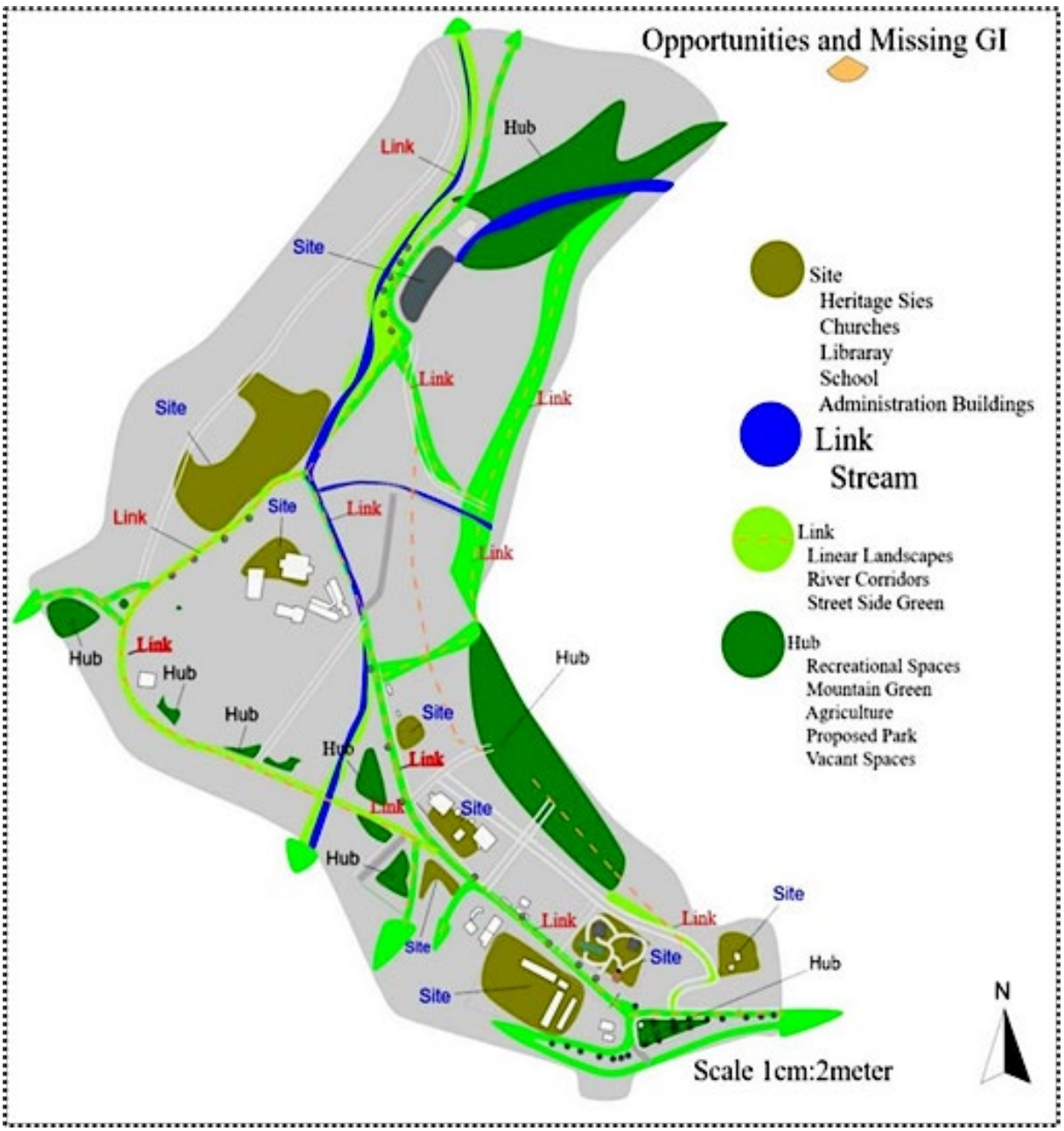



Figure 35 Elements of GI, Linkage, and Hubs

### 4.4. Anatomy of Design Plan/Recommendation

The investigated green space has developed by different interventions. The intervention for all spaces has the following model designs to solve the fragmentation and to bring a sustainable

integrated system of GI. Green space infrastructure is developed by improving its size, shape, and accessibility. It has included environmental, economic, and social sources in sustainable and integrated development. The vacant spaces, street corridors, existing parks, historical areas, and river buffers should be interlinked and bring a complete network. The next development should have the direction of development for GI (see Figure 16).

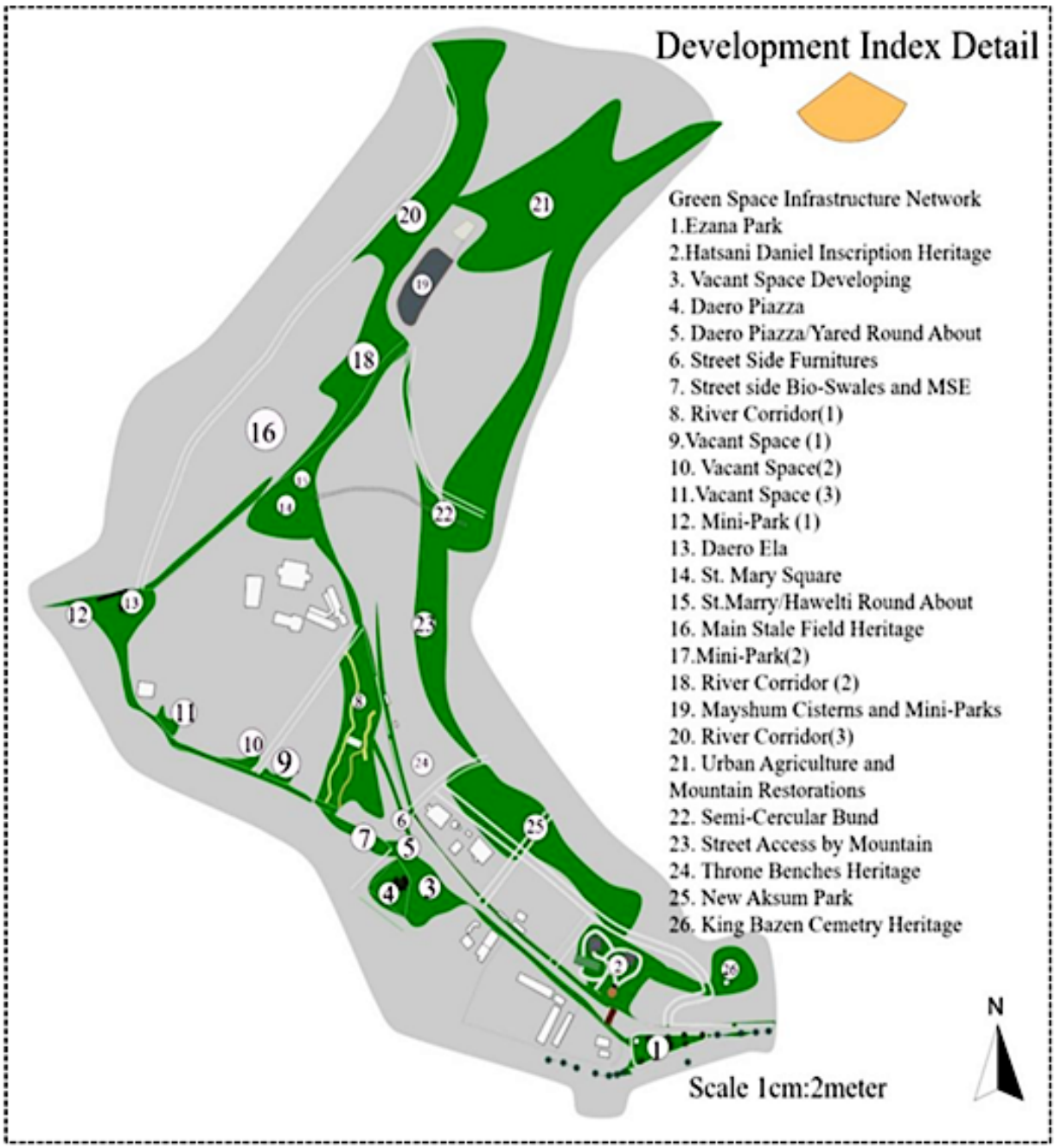


Figure 16 GI Concept Developments

## 5. CONCLUSION

This study's comprehensive analysis of GI quality, using high-resolution 'Copernicus Sentinel-2' imagery and public perception surveys, has yielded several critical insights:

1. Satellite Image Analysis Results: The Normalized Difference Vegetation Index (NDVI) results (ranging from 0.1 to 0.5) indicated a predominance of grass or shrubs across 50.02 hectares, signifying a lack of healthy, dense vegetation and large canopy trees in the study

area. The Normalized Difference Built-up Index (NDBI) ranged from -0.193 to 0.253, with values from -1 to 0 indicating water bodies and 0 to +1 indicating built-up areas. The Built-Up (BU) index results further delineated non-built areas (-1 to 0) from built surfaces (0 to +1). The Built Area Ratio (BAR) was calculated as 13.6%, suggesting limited construction but a lack of integrated network development.

2. Stormwater Management Analysis: Examining stormwater systems revealed traditional permeability patterns in the catchment area. Water flowed from higher to lower elevations, with soil erosion from the eastern rocky surfaces and deposition along river/stream banks. The steep, rocky terrain inhibited groundwater infiltration, impacting the overall stormwater management.
3. User Perceptions of GI: Survey results indicated that users frequently visited GI spaces 3-5 times per week, primarily for socializing (20.5%) and relaxation (18.9%). Preferred GI spaces were those near homes, such as mini-parks and cultural markets (e.g., Daero Piazza and Ezana Park). However, regular maintenance of these spaces was reportedly lacking. Participants expressed a willingness to contribute to GI maintenance through personal labor (25.5%) or by keeping their surroundings clean (22%), conditional upon adequate facilitation by government officials.

The overall quality of GI assessed through area proximity, connectivity, economic integrity, social attractiveness, and ecological preservation was suboptimal. Critical elements such as sites, hubs, and links within the green infrastructure network were not effectively interconnected. Additionally, integrating other infrastructures like circulation systems, roads, water lines, power lines, and pedestrian paths was insufficient.

## 6. ACKNOWLEGEMENT

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# ASSESSMENT OF INFRASTRUCTURE DEVELOPMENT APPROACH IN NEWLY CREATED DISTRICTS IN ZAMBIA: CASE STUDY

Chimanga Kabwe[1*], Musonda Innocent[1], Franco Muleya[2]

[1]University of Johannesburg, South Africa
[2]Copperbelt University, Zambia

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## ABSTRACT

This article evaluates the infrastructure development plans in Zambia's newly established districts, primarily focusing on assessing their effectiveness. Infrastructure development encompasses various strategies, and this study investigates the factors influencing the selection of these strategies for implementing infrastructure projects in Zambia. Through structured interviews and questionnaires distributed to 500 respondents, the research highlights the critical role of community involvement. Communities play a pivotal role in identifying essential amenities, setting priorities for infrastructure construction, incorporating their ideas, and participating in the planning process for executing infrastructure projects. The analysis reveals that community members held varying perspectives on the significance of infrastructure in fostering community integration. However, it also indicates that community involvement in these initiatives was below the desired levels, potentially leading to infrastructure projects that may not entirely align with community preferences. This research underscores the vital importance of infrastructure development, as it establishes the foundation for an improved quality of life encompassing health, education, water supply, sanitation, and transportation.

*Keywords*: Infrastructure; Development; Zambia; Districts; Strategies

## 1. INTRODUCTION

Infrastructure development is pivotal in fostering economic and social development, making it a fundamental requirement for nations aiming to achieve long-term stability and growth. According to Kanzadi and Heidari (2018), quality public infrastructure is essential for successful trade liberalization strategies and resource optimization, thereby driving export growth. Additionally, investments in infrastructure have been identified as effective tools for reducing income inequalities (Irshad & Ghafoor, 2023). Similarly, Derks and Romijn (2019) argue that considering what accounts for infrastructure performance, especially in Africa, demands a thorough comprehension of the institutional arrangements and the incentives governing its delivery.

A robust infrastructure forms the backbone of any society, delivering essential services encompassing energy, water, waste management, transport, and telecommunications (Thacker et al., 2019). In the context of an economy's functionality, infrastructure comprises economic and social components, making it indispensable for economic competitiveness. Infrastructure encompasses many facilities and services, including highways, mass transit, hospitals, education institutions, utilities like electricity and water supply, and waste treatment systems (Thacker et al., 2019). The global increase in investments in infrastructure projects, particularly in low- and middle-income countries, has been driven by a growing body of evidence supporting a positive correlation between infrastructure expenditure and economic growth (Babatunde, 2018; Toader et al., 2018).

*Corresponding author's email: kchimanga@yahoo.com
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Political considerations play a crucial role in governmental decision-making for infrastructure projects, often prioritizing national interests over economic viability. Governments might favor projects that align with political agendas or electoral gains, as seen in decisions to build new ports or manufacturing facilities (Ncube, 2020). However, the contemporary global trade environment demands that investments yield clear economic and public benefits, necessitating a selection model based on reliable data and financial models (Adegun, 2020).

Developmental states employ strategies like offering incentives to local entrepreneurs for state-led industrialization, emphasizing state control over finance and bureaucracy. This approach, exemplified by China's substantial infrastructure investments, demonstrates the state's role in reshaping the socio-economic landscape (Pradhan et al., 2018; Shen & Shen, 2022). China's investment in rural infrastructure development is a case in point, illustrating how government initiatives can rejuvenate both physical and social infrastructure.

Similarly, many African and Latin American countries have adopted state-led development strategies post-independence, resulting in significant advancements in education, health, and economic growth. Governments in these regions have played a pivotal role in sectors like energy and automotive, contributing to infrastructure and social services, thus driving substantial economic growth (Chimhowu et al., 2019; Ovadia & Wolf, 2018).

Community-based development (CBD) emphasizes empowering communities in sustainable development, with governments integrating these initiatives into policy frameworks (Kardes et al., 2019; Thacker et al., 2019). CBD involves direct community control in crucial decisions, including investment management. The approach positions communities as development agents, transforming collaboration based on core principles reflecting local visions and priorities (Adshead et al., 2019).

Debates comparing state-led and community-led infrastructure strategies highlight the shift from neoliberal models to community-centric approaches, emphasizing development relevance to beneficiaries. This shift fosters civil society's role in development, enhancing social cohesion and participatory governance (Gberevbie et al., 2017). Post-1964, Zambia focused on infrastructure development as a key economic strategy, particularly since the early 1990s. The government's investment in infrastructure aimed at enhancing regional and global economic integration, recognizing its dual role in state and global economics (Massey, 2022). From 2012 to 2018, Zambia prioritized infrastructure development in new districts, aiming to improve social services and address community needs. This strategy aimed at poverty alleviation and economic growth through decentralizing public services (Ngoma et al., 2020).

However, challenges and delays were observed in implementing these infrastructure projects. An audit of contracts awarded for various infrastructure development projects revealed stalled or unstarted projects, highlighting inefficiencies in execution. Moreover, an MHID study in late 2018 found that some projects were only 50% complete lacking clear timelines for completion. The study objective is to evaluate the Infrastructure Development Approach implemented in the recently established districts of Zambia.

## 2. METHODS

### 2.1. Data Collection and Analysis Approach

In this study, methodological triangulation was employed to gather comprehensive and complementary insights from various stakeholders related to the research. The primary data collection tool was a questionnaire, chosen for its flexibility in collecting data. The semi-structured questionnaire, featuring both open-ended and closed-ended questions, was administered to community members in the selected study provinces. This approach allowed for collecting

quantitative data regarding community members' perceptions of state-led infrastructure projects delivered through settlement upgrades in Zambia.

Furthermore, in-depth data was needed to understand the selection process determinants and the impact of the settlement model on infrastructure development in Zambia. Semi-structured interviews were conducted with government officials and project consultants to achieve this. These interviews provided a more detailed and qualitative perspective than other data collection methods. By combining quantitative and qualitative approaches, this study aimed to address potential weaknesses in one method with the strengths of the other.

### 2.2. Sampling Procedure

Purposive sampling was used to select community members between the ages of 18 and 60 with knowledge of infrastructure development projects in their respective districts. Additionally, quota sampling was employed to select government officials and project consultants in the selected districts and at MHID. This approach allowed for the targeted sampling of a subgroup crucial to the study. The study aimed to collect data from 520 individuals, comprising 500 residents from the three newly created districts in the selected provinces and 20 government officials and project consultants. A response rate of 90% was achieved among residents, with 450 completed and returned questionnaires deemed acceptable (Hendra & Hill, 2019). Among the targeted 20 interviewees, 11 interviews were conducted, resulting in a response rate of 55%.

### 2.3. Data Analysis

Descriptive statistics were used to analyze the collected data to establish the Infrastructure Development Approach in Newly Created Districts in Zambia. Mean deviation, standard deviation, and percentage scores were closely examined using SPSS software. Data collected using questionnaires was initially inspected in preparation for coding and entering into the SPSS V 21 program to produce frequencies and percentages. SPSS was used because it allows for statistical, modeler, and text analysis and visualization designs for questionnaire responses, Likert scales were coded as follows: "Strongly Agree" = 1, "Strongly Disagree" = 5, and intermediate responses received values between 1 and 5. A five-point Likert scale was chosen for its ease of understanding and respondent-friendly nature.

Quantitative data were meticulously reviewed for inconsistencies to ensure the accuracy of the findings in assessing the research problem. The SPSS software, known for its statistical analysis, modelling, text analysis, and visualization capabilities, was employed for data processing and analysis.

## 3. RESULTS

### 3.1 Response Rate

Five hundred questionnaires were distributed to community members in selected provinces, including Western, Eastern, and Lusaka. Four hundred fifty respondents completed the questionnaires, resulting in a robust response rate of 90%. This response rate is visually depicted in the Figure 1 below.

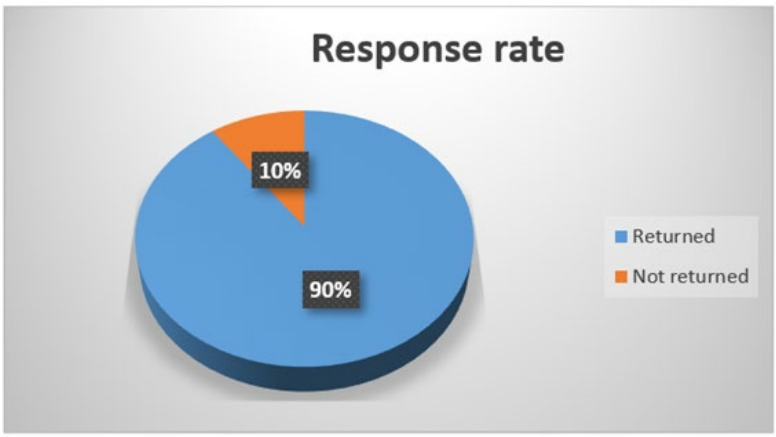


Figure 1 Response Rate

### 3.2. Demographics of Respondents

3.2.1. Age of the Respondents

Analysis of the respondents' ages revealed several key insights. The modal age group was 31–40 years, constituting the largest segment at 33.3% of the total participants. The second-highest frequency was observed among those below 30 years, accounting for 25.6%. Respondents aged 41 and 50 years represented 23.6% of the total responses. Conversely, individuals aged 51 and above had the lowest frequency, making up 17.6% of the respondents.

These findings suggest that a significant majority, approximately 74.4%, of the respondents were aged 30 years or older, indicating a mature demographic capable of comprehending developmental issues and local community agendas. The table 1 below provides a detailed breakdown of the age distribution among the respondents.

Table 1 Age of the Respondents

| Age | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Below 30 | 115 | 25.6 | 25.6 | 25.6 |
| 31-40 years | 150 | 33.3 | 33.3 | 58.9 |
| 41-50 years | 106 | 23.6 | 23.6 | 82.4 |
| 51 and above | 79 | 17.6 | 17.6 | 100.0 |

3.2.2. Level of Education

The respondents' education level is a crucial factor in understanding their ability to comprehend and engage with developmental projects, particularly infrastructure initiatives within their respective communities. Table 2 provides a comprehensive summary of the numerical distribution of respondents' education levels.

The data reveals several key insights regarding the education levels of the respondents:

- Respondents with primary education only accounted for 17.1%.
- Those who completed secondary education without a formal certificate constituted 21.6%.
- The majority, representing 40.9%, possessed a Grade 12 certificate.
- Diploma holders made up 12.2% of the total respondents.
- Individuals with degrees comprised 6.2%.

- A smaller percentage had higher education qualifications, with 0.9% having Master's degrees and 1.1% holding PhDs.

Table 2 Level of Education

| Level of Education | Frequency | Precent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Primary school | 77 | 17.1 | 17.1 | 17.1 |
| Secondary school | 97 | 21.6 | 21.6 | 38.7 |
| Grade 12 certificate | 184 | 40.9 | 40.9 | 79.6 |
| Diploma | 55 | 12.2 | 12.2 | 91.8 |
| Degree | 28 | 6.2 | 6.2 | 98.0 |
| Master's Degree | 4 | .9 | .9 | 98.9 |
| PhD | 5 | 1.1 | 1.1 | 100.0 |
| Total | 450 | 100.0 | 100.0 | |

Therefore, approximately 44.2% of the respondents had received formal education, including those with Grade 12 certificates, diplomas, degrees, Master's degrees, and Ph.Ds. Furthermore, 82.9% of the respondents had attained at least some secondary schooling level

### 3.3. Descriptive Statistics

The rationale for conducting the Descriptive statistics was to have a basic understanding of the data-informed and the pattern of scoring by the respondents. As a general basic summary of what descriptive statistics intends to show, statistical measures focus on measures of central tendency and variability. The extractive results are in the descriptive table discussions that follow.

#### 3.3.1. Public Opinion on Communities's Basic Amenities Construction by the Authorities

The Descriptive Statistics conducted in this study aimed to provide a basic understanding of the data and the scoring patterns of the respondents. The key focus of the statistical measures included measures of central tendency and variability. The results are discussed in the following table 3.

Table 3 Public opinion on the construction of basic amenities in their communities obtained through authorities

| | N | Range | Mean | Std. Deviation | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| Public opinion: letters written to us before the start of projects | 450 | 3 | 2.01 | .638 | .407 | .094 | .115 | -.214 | .230 |
| Public opinion: questionnaires distributed among community members | 450 | 4 | 2.20 | .858 | .736 | 1.341 | .115 | 2.412 | .230 |
| Public opinion: public hearings organized by government officials (e.g., MPs, Ward Councillors) | 450 | 4 | 3.57 | 1.127 | 1.271 | -.654 | .115 | -.433 | .230 |
| Public opinion: engaging us on various social media | 450 | 3 | 2.45 | .754 | .569 | .355 | .115 | -.246 | .230 |

| | N | Range | Mean | Std. Deviation | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| platforms (e.g., Facebook, WhatsApp) | | | | | | | | | |
| Public opinion: through door-to-door sensitization exercise | 450 | 2 | 2.15 | .636 | .405 | -.138 | .115 | -.588 | .230 |
| Valid N (listwise) | 450 | | | | | | | | |

The findings from the table indicate public opinion on the construction of basic amenities in communities obtained through various means. Here are some key insights:

a) Four variables received negative feedback from the community members, with a mean score below 3.5, indicating disagreement. These variables include public opinion collected through letters, questionnaires, social media engagements, and door-to-door sensitization before constructing basic amenities.
b) Public opinions obtained through public hearings organized by government officials received a positive response, with an average mean of 3.57. This suggests that community members agreed with public opinion conducted through public hearings before constructing basic amenities.
c) The data displayed low deviations, as indicated by the standard deviation and variance, implying consistency in the data and a concentration of opinions within the same range.
d) Skewness was used to measure the asymmetry of the data. Public opinions collected through letters, social media platforms, and door-to-door sensitization had almost zero skewness. However, opinions obtained through public hearings were left-skewed, reflecting positive responses, while opinions gathered through questionnaires were right-skewed, indicating a negative response.
e) Kurtosis measured the presence of outliers, and the data showed low kurtosis values, signifying that the data was uniformly distributed.

Additionally, the interviewees provided valuable insights into the challenges and strategies of community involvement in infrastructure projects, emphasizing the importance of effective communication and community participation from project inception.

### 3.3.2. Relevance of the Infrastructure Built in Communities

The study aimed to assess the relevance of infrastructure to communities by considering their involvement in selecting amenities, prioritizing construction, incorporating their ideas, empowering them with necessary infrastructure, and participating in planning for implementation. The following table 4 provides a summary of the descriptive statistics for these aspects:

Table 4 Descriptive Statistics of Relevance of the Infrastructure Built to Communities

| | N | Range | Mean | Std. Deviation | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| Infrastructure relevant to communities: communities were involved in selecting amenities that they needed | 450 | 4 | 2.21 | .944 | .890 | .887 | .115 | .648 | .230 |
| Infrastructure relevant to communities: communities were involved in prioritizing the construction of infrastructure | 450 | 2 | 2.16 | .588 | .345 | -.045 | .115 | -.263 | .230 |
| Infrastructure relevant to communities: communities' ideas were incorporated into the infrastructure built | 450 | 4 | 2.50 | .923 | .852 | .565 | .115 | .206 | .230 |
| Infrastructure relevant to communities: communities have been empowered with necessary public infrastructure | 450 | 3 | 2.35 | .833 | .695 | .251 | .115 | -.454 | .230 |
| Infrastructure relevant to communities: community members participated in planning for the implementation of built infrastructure | 450 | 3 | 2.10 | .901 | .812 | .518 | .115 | -.460 | .230 |
| Valid N (listwise) | 450 | | | | | | | | |

The findings from the table indicate the relevance of infrastructure from the perspective of community involvement. Here are some key insights:

a) The mean average for these five areas was 2.264, with the highest mean of 2.50 from the aspect of community member idea incorporation and the lowest mean of 2.10 from non-involvement of community members in planning for the implementation of built infrastructure. These mean values suggest that community members disagreed on the relevance of infrastructure in all aspects of community incorporation.
b) There was little deviation in the data, with standard deviation and variance indicating uniformity in the data distribution.
c) Skewness was present in three aspects, showing an asymmetry skewed to the right, indicating a negative response. These aspects included involving communities in selecting what they needed, incorporating their ideas, and involving them in the planning for implementation.
d) Kurtosis values confirmed the uniformity in the data distribution.

Interviewee GOVZ-05 highlighted the challenges faced by the government in working closely with Ward Development Committees (WDCs) and the importance of community involvement in project development. The interviewee emphasized that community preferences and local knowledge play a significant role in determining infrastructure priorities.

3.3.3. Community Participation in Communities' Infrastructure Planning and Implementation

The study explored community participation in the planning and implementation of infrastructure projects within communities. The following table 5 provides a summary of the descriptive statistics for various aspects of community participation:

Table 5 Descriptive Statistics for Community Participation in Planning and Implementation of Infrastructure in Communities

| | N | Range | Mean | Std. Deviation | Variance | skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| Communities' participation: in project planning meetings | 450 | 3 | 2.85 | .891 | .794 | -.169 | .115 | -.929 | .230 |
| Communities' participation: in infrastructure developed as our ideas were incorporated in designing infrastructure | 450 | 3 | 2.56 | .774 | .599 | .378 | .115 | -.502 | .230 |
| Communities' participation: in decision-making committees on infrastructure development | 450 | 4 | 2.66 | 1.046 | 1.093 | .351 | .115 | -.580 | .230 |
| Communities' participation: in deciding the location of various infrastructure developed in the district | 439 | 4 | 2.78 | 1.097 | 1.203 | .119 | .117 | -.738 | .233 |
| Communities' participation: in actions taken to ensure successful implementation of projects | 444 | 4 | 3.61 | 1.262 | 1.592 | -.560 | .116 | -.838 | .231 |
| Valid N (listwise) | 433 | | | | | | | | |

The findings from the table suggest the following insights:

a) Four aspects of community participation, including project planning, infrastructure design, decision-making committees, and deciding project locations, had mean scores below three. This indicates that community members disagreed with participating in these aspects of infrastructure development.
b) Only community participation in actions taken to ensure the successful implementation of projects had a mean score above three (3.61), indicating that community members somewhat agreed with this issue.

c) Skewness measurements showed that community participation in actions to ensure the successful implementation of projects was skewed to the left, indicating positive feedback on this matter. However, other aspects were not skewed similarly, suggesting a lack of community involvement.
d) Kurtosis values indicated a uniform distribution of frequencies for all investigated aspects.

Interviewees provided valuable insights into the challenges and opportunities related to community participation. Interviewee PCON-03 highlighted the lack of community-based associations and knowledge among rural villages in Zambia, inhibiting effective engagement in project planning. Interviewee PCON-05 emphasized the minimal community participation, suggesting that community preferences may not have been fully considered in infrastructure projects. GOVZ-02 recognized the importance of Ward Development Committees (WDCs) but noted that exploration of the reality in districts with WDCs was limited during infrastructure development.

These findings underscore the need for strategies to enhance community participation, informed decision-making, and improved communication channels to ensure successful infrastructure projects in communities.

### 3.3.4. Sustainability of infrastructure projects in Zambia

The sustainability of infrastructure projects in Zambia is paramount, especially in the face of climate change challenges in the Sub-Saharan Africa (SSA) region. Climate projections indicate that regions, including southern Zambia, may experience a significant decrease in precipitation and an increase in consecutive dry days if global temperatures exceed 1.5oC above pre-industrial levels (Zulu et al., 2023). To address these challenges, there is an urgent need for policies and initiatives to mitigate climate change impacts in the region. However, numerous factors hinder the successful implementation and widespread support for sustainability initiatives in many SSA countries.

Current literature reveals many challenges that hinder the successful implementation of sustainable building practices. Extensive studies have identified 175 challenges related to sustainable development (Álvarez Jaramillo et al., 2018). Factors hindering sustainability initiatives are diverse and include cost concerns, economic factors, policy limitations, the role of construction professionals, and client-related issues (Tokbolat et al., 2019).

One recurring challenge in sustainable construction is the perception of higher costs compared to traditional methods. This perception arises from the belief that sustainable resources are limited, and that achieving sustainability takes longer (Durdyev et al., 2018). Sustainable practices often require extended timeframes to recover costs (Tokbolat et al., 2019).

Government incentives, legislative restrictions, and regulations are critical for promoting sustainable building but are often perceived as inadequate, further hindering its implementation (Tokbolat et al., 2019). Construction experts, who play a vital role in sustainable infrastructure, may impede its acceptance due to limited skills, resistance to change, and inadequate training (Durdyev et al., 2018). Client-related challenges include a lack of demand for sustainable building due to limited environmental awareness and understanding of its benefits (Durdyev et al., 2018).

Despite these challenges, there are compelling reasons to embrace sustainable construction. It can reduce costs over a building's lifespan, offer a favorable return on investment, enhance marketability, and increase the monetary value of structures. Sustainable infrastructure is also associated with an improved corporate image, contributing to a company's reputation and environmental sustainability efforts (Durdyev et al., 2018; Tokbolat et al., 2019).

Furthermore, environmental concerns drive the adoption of sustainable building practices, aiming to reduce the impact on nature, improve indoor spaces, and enhance the well-being of individuals.

Effective government policies and regulations can either hinder or support sustainable construction, depending on their design and level of encouragement (Phatak and Sople, 2018).

In conclusion, while challenges persist in the path to sustainable infrastructure, the potential benefits of cost savings, enhanced corporate image, environmental consciousness, and compliance with regulations make it a compelling endeavour for Zambia and the broader SSA region. Effective policies and regulations, combined with increased awareness, are essential in promoting sustainable building practices and fostering a culture of sustainability.

## 4. DISCUSSION

This research study has provided valuable insights into the infrastructure development approach in newly created districts in Zambia. The analysis highlights several key findings that underscore the importance of community engagement and participation in infrastructure projects.

One prominent theme that emerges from the analysis is the critical need for the government to involve the community in the decision-making process regarding the construction of basic amenities. Neglecting the public's opinion can lead to the construction of amenities the community does not need, ultimately wasting valuable state resources. Furthermore, such infrastructure may not effectively improve the quality of life for the local population. The government must identify stakeholders' expectations early in the project, consider job skills within the community, and improve local infrastructure capacity.

The challenges in disseminating information about government projects, particularly in areas with poor road networks or limited communication channels, highlight the importance of effective communication strategies. Ensuring project information reaches the local communities is vital for their engagement and participation in decision-making.

The research also draws attention to the advantages of including the public in addressing infrastructure development projects' social and environmental consequences. Studies conducted in other regions, such as the research in Thailand by Rojanamon et al. (2012), demonstrate the benefits of providing project information to the local population and considering the demands of all groups throughout the project's lifecycle.

The absence of community involvement in infrastructure planning is identified as a significant challenge. This oversight can lead to poorly designed projects, increased project costs, and a mismatch between community needs and project outcomes. To address this, it is recommended that the government focus on enhancing the knowledge of rural communities about their rights and entitlements, enabling them to participate effectively in project planning meetings.

Stakeholder engagement throughout each project stage is emphasized as essential for obtaining support, managing expectations, and mitigating risks. Engaging with stakeholders, including local communities, can help prevent delays, cost overruns, and project failure.

Community participation in implementing infrastructure projects is highlighted to foster a sense of community belonging, purpose, contribution, and acceptance. This aligns with findings from other studies, such as those by Barclay & Klotz (2019) and Di Maddaloni & Davis (2017), emphasizing the importance of considering the impact on all stakeholders, including local people, from the early stages of project development.

In summary, the challenges in infrastructure development in Zambia primarily revolve around the need for greater community engagement and consideration. Addressing these challenges requires involving the public in decision-making, prioritizing infrastructure projects, and actively incorporating their ideas. Effective communication, stakeholder engagement, and community

participation throughout project implementation are essential for successful infrastructure development in newly created districts.

## 5. CONCLUSION AND RECOMMENDATIONS

The study's conclusions and recommendations shed light on the crucial role of community involvement in infrastructure projects and highlight the need for more participatory governance methods to enhance social and environmental sustainability. Here is a summary of the key points:

1) Infrastructure Relevance to Communities: The study found that community members disagreed on the relevance of infrastructure in various aspects of community incorporation. This suggests that their opinions were not fully considered in selecting amenities, prioritizing infrastructure projects, incorporating ideas, and planning for implementation. This misalignment between community needs and project decisions can result in a lack of public acceptance and potential project failure.
2) Limited Community Participation: The research revealed minimal community participation in the projects. This lack of participation implies that the wishes and preferences of the local population may not have been fully considered during the construction of infrastructure. To address this, the government and relevant agencies must develop practical strategies to facilitate community participation and ensure that all stakeholders are well-informed and represented in decision-making processes.
3) Creating Feasible and Workable Strategies: The study recommends that the government collaborates with other agencies to create feasible and workable strategies for community participation. These strategies should motivate and guide communities in actively participating in infrastructure projects. By involving the local population in decision-making, projects are more likely to align with community needs and gain public acceptance.
4) Participatory Governance Methods: To overcome social disputes arising from infrastructure projects and promote respect for human rights, the study suggests the establishment of more participatory governance methods. These methods should facilitate communication between infrastructure corporations, the government, and local communities. By shifting the decision-making process to be more inclusive and sustainable, infrastructure projects can become socially profitable and better aligned with community values and needs.

The study underscores the importance of community involvement in infrastructure development and recommends a shift toward more participatory and inclusive governance methods. By actively engaging communities, infrastructure projects can enhance their social and environmental sustainability while respecting human rights and local preferences.

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**Declaration of interest**

I declare no potential conflicts of interest associated with the research presented in the article "Assessment of Infrastructure Development Approach in Newly Created Districts in Zambia." Any new conflicts of interest arising during the publication process will be promptly communicated to the journal, and appropriate actions will be taken to address them.

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